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Age and Growth of the Whitefish, *Coregonus clupeaformis*, of Munising Bay, Lake Superior[1]

THOMAS A. EDSALL

U. S. Bureau of Commercial Fisheries, Biological Laboratory
Ann Arbor, Michigan

ABSTRACT

This study is based on a sample of 415 whitefish collected in 1953 from an unexploited population in Munising Bay, Lake Superior. Gill-net and trawl catches had different length-frequency distributions and age compositions, but estimates of growth from the two catches were very similar. The body-scale relation is a straight line with an intercept of 1.5 inches. Weight of Munising Bay whitefish captured in June increased as the 3.17 power of the length. Growth in length and weight of Munising Bay whitefish was the slowest yet reported from Great Lakes waters. Munising Bay whitefish required nearly 8 years to reach a length of 10 inches and a full 13 years to reach 15 inches. Slightly more than 8 years were required to reach a weight of 8 ounces and a little less than 14 years to reach 1 pound. The sex ratio of the Munising Bay whitefish exhibited no systematic change with an increase in age. The entire sample for which ages were determined contained 52 percent males. Munising Bay whitefish matured at much shorter lengths but at a greater age than reported for other Great Lakes whitefish populations. The smallest mature males were in the 11.5- to 11.9-inch length interval (age-group VII) and all males longer than 14.4 inches (age-group XII) were mature. The first mature females appeared at 12.0-12.4 inches (age-group X) and all females longer than 14.9 inches (age-group XII) were mature. The more rapidly growing individuals matured earlier than the slow-growing ones.

INTRODUCTION

The present paper is a contribution to a continuing study of the U. S. Bureau of Commercial Fisheries designed to determine the extent of the differences in growth rate among local populations of the whitefish, *Coregonus clupeaformis*, of Lake Superior.

The Munising Bay (Figure 1) whitefish population is of special interest because it is unexploited and has an extremely slow growth rate. Lack of exploitation is attributable both to statutes which prohibit commercial fishing in Munising Bay and to the slow growth of individual fish, which prevents migrants from contributing materially to the commercial whitefish fishery immediately outside the bay. No explanation for the slow growth rate can be offered as a result of this study. The Munising Bay whitefish population, however, is apparently much denser than other Lake Superior whitefish populations, because fishing records for the Bureau's vessel *Cisco* indicate that many more whitefish were caught per unit of effort in Munising Bay than elsewhere in Lake Superior. Munising Bay whitefish are also most abundant at greater depths (22-38 fathoms) than are ordinarily frequented by Great Lakes whitefish. The temperatures at these depths are very low; the maximum of 45° F. is reached in late September.[2]

MATERIALS AND METHODS

Data from the 415 whitefish collected in Munising Bay in June and August 1953 dur-

[1]This study was submitted as a master's thesis in the Department of Fisheries, University of Michigan.

[2]Temperature data taken during the 1953 and 1959 operations of the U. S. Bureau of Commercial Fisheries vessel *Cisco*.

TABLE 1.—*Collections of Munising Bay whitefish, 1953*

Gear	Date of capture							Total
	June 17	June 18	June 21	June 22	August 14	August 15	August 16	
Trawl	82	38	5	0	0	—	—	125
Gill net	91	—	—	163	27	8	1	290
Total	173	38	5	163	27	8	1	415

ing the operations of the U. S. Bureau of Commercial Fisheries vessel *Cisco* are the basis for this study (Table 1). Information on length, weight, sex, and state of maturity was recorded for each fish. Scales were taken from 252 fish (all but the 163 fish captured on June 22).

All whitefish were caught by nylon gill nets and otter trawls. Individual gill nets were 250 feet long and 6 feet deep; each net was one in a series of eight mesh sizes ranging from 1 to 4½ inches.[3] Gill nets were fished in gangs with each gang consisting of group of gill nets of different mesh siz joined end to end. Gangs were set on the b tom, usually across the contours and left ov night. The trawls were 35 feet wide at t wings and 36 feet long with mesh sizes fr 1½ to 2½ inches in the wings and body a ½ inch in the cod ends. Trawl tows we made on the bottom, generally along the co tours, and usually lasted 10 minutes.

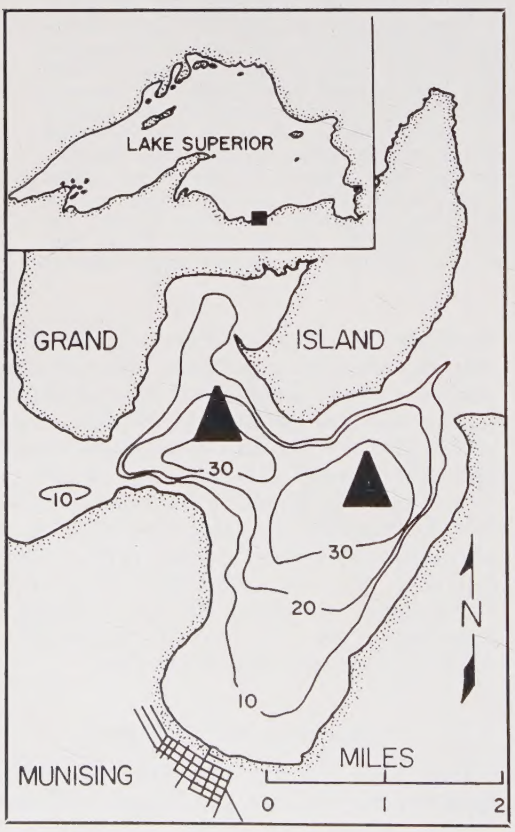

FIGURE 1.—Munising Bay, Lake Superior. Fishing locations shown by shaded triangles; depth contours are in fathoms.

[3]Mesh sizes are stretched-mesh measurements.

Length distributions of fish in the Ju trawl and gill-net catches (Table 2) dif substantially. The trawl sample has a sing strong mode in the 11.0- to 11.4-inch leng interval, while the length-frequency distri tion in the gill-net sample is skewed to the l and lacks the strong mode of the trawl sam at 11.0 to 11.4 inches. The average to lengths of fish in the June trawl and gill-n samples were 11.6 and 12.1 inches, resp tively. Growth estimates of fish in catch from the two gears were closely similar, b estimates of age composition differed. A br discussion of the significance of the differen

TABLE 2.—*Length distribution of Munising whitefish caught by gill nets and trawls*

Length interval (inches)	Trawl		Gill net	
	Number	Percentage	Number	Percent
7.0- 7.4	2	1.6	—	—
7.5- 7.9	1	0.8	—	—
8.0- 8.4	2	1.6	—	—
8.5- 8.9	3	2.4	—	—
9.0- 9.4	4	3.2	1	1.1
9.5- 9.9	10	8.0	3	3.3
10.0-10.4	12	9.6	8	8.8
10.5-10.9	11	8.8	13	14.3
11.0-11.4	21	16.8	11	12.1
11.5-11.9	9	7.2	9	9.9
12.0-12.4	12	9.6	12	13.2
12.5-12.9	11	8.8	11	12.1
13.0-13.4	7	5.6	9	9.9
13.5-13.9	5	4.0	4	4.4
14.0-14.4	7	5.6	3	3.3
14.5-14.9	2	1.6	1	1.1
15.0-15.4	3	2.4	2	2.2
15.5-15.9	2	1.6	1	1.1
16.0-16.4	1	0.8	—	—
16.5-16.9	—	—	2	2.2
17.0-17.4	—	—	1	1.1
Total	125	—	91	—
Average length	11.6	—	12.1	—

in length distributions of catches from gill nets and trawls with respect to age is presented in the section on age composition.

The total length (tip of the head to the tip of the tail, with lobes compressed) of each fish was read from a measuring board in the field and recorded to the nearest 0.1 inch. Fresh weights of the smaller whitefish were determined to the nearest 0.1 ounce on a spring scale with an 18-ounce capacity. Fish heavier than 18 ounces were weighed on a larger spring scale to the nearest full ounce. Scale samples were removed from the left side midway between the lateral line and the midpoint of the base of the dorsal fin and were placed in an envelope on which the length, weight, sex, state of gonads, date, gear, and location of capture were recorded.

The sex and state of maturity of the gonads were determined by gross examination. Mature fish were those judged to be ready to spawn in the fall of that same year. Impressions of the scales were made in cellulose acetate (Smith, 1954) and were magnified 43 diameters for study by means of a microprojector similar to that described by Moffett (1952). Measurements of scale diameters were made through the focus along the cephalo-caudal axis from the projected scale image as prescribed by Van Oosten (1923).

The ages of fish were determined from the annuli on their scales. Since each fish was considered to have passed into the next higher age group on January 1 a "virtual" annulus was accredited at the edge of the scale from January 1 to the date the current season's annulus actually was completed (Hile, 1948). Ages are expressed by Roman numerals corresponding to the number of annuli.

Annuli were characterized by a change in the spacing and thickness of the circuli in the anterior and lateral portions of the scale and by crossing over in the posterior-lateral portions. On many scales accessory marks and other odd patterns in the spacing and thickness of the circuli, especially near the margin, prevented age determination with reasonable accuracy. As a result, the scales of many whitefish (17.6 percent of the June catch) were discarded as unreadable.

The average total length of fish in the entire June sample was 11.8 inches, and the average total lengths of the aged and unaged portions of the sample were 11.6 and 12.9 inches, respectively. The greater average length of the unaged portion indicates that many of these fish were members of the older age groups. Although the records of age composition were biased by the rejection of numerous large fish, the calculated lengths gave no evidence of bias to growth estimates through the selective discarding of slow-growing individuals.

The 36 whitefish captured in August were excluded from age analysis because annulus formation was in progress at this time. This fact, and the great irregularity in the growth of individual fish, frequently made it impossible to decide whether marginal growth had been completed in the previous or the current season. Whitefish caught in June presented no such difficulty because growth had not yet started.

AGE COMPOSITION

The age composition of the trawl and gill-net samples (Table 3) differed both in relative strength of age groups and in average age. Age distributions of both trawl and gill-net samples were unimodal, but of the two the gill-net distribution was the more strongly dominated by a single age group. Age-groups II-XIII were represented in the trawl sample (age-group VI dominant — 19.0 percent) whereas age-groups IV-XVI were represented in the gill-net samples and age-group VII was strongly dominant (31.5 percent). The representation of whitefish in neighboring age groups fluctuated much more widely in the

TABLE 3.—*Age composition of the Munising Bay whitefish caught by gill nets and trawls*

Age group	Trawl		Gill net	
	Number	Percentage	Number	Percentage
II	2	1.9	—	—
III	5	4.8	—	—
IV	11	10.5	6	8.2
V	14	13.3	5	6.8
VI	20	19.0	11	15.1
VII	14	13.3	23	31.5
VIII	13	12.4	9	12.3
IX	9	8.6	7	9.6
X	6	5.7	9	12.3
XI	6	5.7	1	1.4
XII	4	3.8	—	—
XIII	1	1.0	1	1.4
XVI	—	—	1	1.4
Total	105	—	73	—
Average number of annuli	6.9	—	7.4	—

gill-net sample and exhibited a less regular trend than in the trawl sample. The average age of fish in the gill-net samples (7.4 years) was 0.5 year greater than in trawl samples (6.9 years). The data of Table 3 do not appear to justify speculation as to the relative strength of the year classes. The differences between the age compositions of the trawl and gill-net samples, especially in view of the exceptionally slow growth rate of this population, are attributed to the differences in the length distributions of the two samples (Table 2).

Although the absence or scarcity of young whitefish in the gill-net sample can be attributed to the difficulty of holding very small fish in gill nets (Hile, 1941), their scarcity in the trawl sample can not. The ½-inch mesh of the cod ends of trawls used was certainly able to retain small whitefish. If small fish had been abundant, they should have been taken in good numbers even though some escaped through the mesh of the trawl body. The scarcity of young whitefish in the trawl sample therefore is believed to be a true reflection of the relative abundance of this segment of the population at the bottom on the deep-water fishing grounds. It is not known, however, whether the absence of young whitefish on the fishing grounds is indicative of a difference in habitat preference or of weak year classes in 1949-51. The decrease in the numbers of Munising Bay whitefish with an increase in age (age-grou VIII-XVI) is typical and undoubtedly flects mortality.

LENGTH DISTRIBUTION OF THE AGE GROUPS

There is considerable range in the length fish in the same age group (Table 4) a extensive overlap between neighboring a groups. Among the better represented a groups the greatest span between the long and shortest individuals of the group was to 4 inches. The better represented length tervals contained fish from four to seven a groups. The overlapping of the distributi was the result of the considerable range lengths of most of the age groups in a stock which the average annual increments growth were relatively small. As a resu length alone is a poor index of age of Mu sing Bay whitefish.

LENGTH-WEIGHT RELATION

The general parabola, $W = cL^n$, where = weight, L = total length, and c and n a empirically determined constants, has be used satisfactorily to describe the gene length-weight relationship of the numero species and stocks of fish. Determination the length-weight relation of the Munisi Bay whitefish was based on the data from 379 fish captured in June and may not be

TABLE 4.—*Length distribution of age groups of Munising Bay whitefish*

Length interval (inches)	Age group												
	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XI
7.0- 7.4	1	1	—	—	—	—	—	—	—	—	—	—	—
7.5- 7.9	1	—	—	—	—	—	—	—	—	—	—	—	—
8.0- 8.4	—	1	—	—	—	—	—	—	—	—	—	—	—
8.5- 8.9	—	2	1	—	—	—	—	—	—	—	—	—	—
9.0- 9.4	—	1	2	—	1	—	—	—	—	—	—	—	—
9.5- 9.9	—	—	5	6	1	1	—	—	—	—	—	—	—
10.0-10.4	—	—	6	6	6	2	—	—	—	—	—	—	—
10.5-10.9	—	—	2	5	6	7	4	—	—	—	—	—	—
11.0-11.4	—	—	1	1	12	13	2	2	—	—	—	—	—
11.5-11.9	—	—	—	—	2	3	8	3	—	—	—	—	—
12.0-12.4	—	—	—	1	2	5	1	2	4	1	—	—	—
12.5-12.9	—	—	—	—	1	6	5	1	—	1	—	—	—
13.0-13.4	—	—	—	—	—	—	2	3	5	1	—	—	—
13.5-13.9	—	—	—	—	—	—	—	2	2	—	1	—	—
14.0-14.4	—	—	—	—	—	—	—	2	3	1	—	—	—
14.5-14.9	—	—	—	—	—	—	—	—	—	1	—	—	—
15.0-15.4	—	—	—	—	—	—	—	1	—	1	1	1	—
15.5-15.9	—	—	—	—	—	—	—	—	—	1	1	1	—
16.0-16.4	—	—	—	—	—	—	—	—	1	—	—	—	—
16.5-16.9	—	—	—	—	—	—	—	—	—	—	1	—	1
Number of fish.....	2	5	17	19	31	37	22	16	15	7	4	2	1
Percentage of total...	1.1	2.8	9.6	10.7	17.4	20.8	12.4	9.0	8.4	3.9	2.2	1.1	0.
Average length....	7.4	8.5	9.9	10.4	11.0	11.4	11.9	12.8	13.4	14.0	15.5	15.6	16.

curately descriptive for other times of the year. Whitefish collected in August were heavier than fish of the same length that were captured in June but there were too few August specimens to establish clearly the extent of the seasonal fluctuation. The length-weight equation, determined by fitting a straight line to the logarithms of the lengths and weights listed in Table 5, was:

$$\log W = 2.5596 + 3.1712 \log L,$$

where W = weight in ounces and L = total length in inches. This equation may also be written in the form,

$$W = 7.4788 \times 10^{-3} L^{3.1712}.$$

TABLE 5.—*Length-weight relationship of Munising Bay whitefish*

[The lengths are the true averages for fish in 0.5-inch groups]

Number of fish	Average total length (inches)	Average weight (ounces)	
		Empirical	Calculated
2	7.3	1.4	1.5
1	7.5	1.6	1.6
2	8.2	2.1	2.2
3	8.8	2.8	2.7
5	9.2	3.1	3.1
14	9.7	3.6	3.7
25	10.2	4.2	4.4
36	10.7	5.1	5.1
56	11.2	6.1	5.9
38	11.7	6.9	6.7
55	12.3	7.8	7.9
40	12.7	8.9	8.9
35	13.2	10.2	9.9
28	13.7	11.4	11.1
16	14.3	12.4	12.7
7	14.7	14.1	13.9
8	15.2	16.3	15.4
4	15.7	16.7	17.1
1	16.4	16.1	19.6
2	16.8	20.8	21.2
1	17.4	26.8	23.7

The value of n indicates that weight increases more rapidly than the cube of the length.

The data of Table 5 indicate a generally good agreement between empirical and calculated weights. The largest discrepancies were at the greater lengths where numbers of fish were small and actual weights great enough to make relatively modest percentage disagreements seem larger.

The weight of whitefish caught in June varies according to maturity and sex (Table 6). Weights of immature male and female fish of the same length did not differ significantly. The mature fish, however, were usually heavier than immature fish, and the mature females were generally heavier than the mature males.

TABLE 6.—*Weight (ounces) of Munising Bay whitefish by sex and maturity*

[Number of fish in parentheses. Fish shorter than 11.5 inches were immature. Sex and maturity data missing for one fish 14.2 inches long]

Total length (inches)	Male		Female	
	Immature	Mature	Immature	Mature
11.5-11.9	6.6 (12)	7.3 (5)	6.9 (19)	6.5 (2)
12.0-12.4	7.7 (23)	8.0 (7)	7.6 (18)	8.4 (7)
12.5-12.9	8.7 (17)	9.2 (7)	8.9 (15)	9.9 (1)
13.0-13.4	9.7 (9)	10.3 (9)	10.3 (14)	11.0 (3)
13.5-13.9	11.3 (9)	11.4 (7)	11.2 (7)	11.8 (5)
14.0-14.4	—	12.1 (7)	12.5 (5)	12.8 (3)
14.5-14.9	—	13.6 (2)	13.8 (3)	15.2 (2)
15.0-15.4	—	16.3 (5)	—	16.3 (3)
15.5-15.9	—	18.8 (1)	—	16.0 (3)
16.0-16.4	—	16.1 (1)	—	—
16.5-16.9	—	20.8 (2)	—	—
17.0-17.4	—	—	—	26.8 (1)
Number of fish	70	53	81	30

BODY-SCALE RELATIONSHIP

Van Oosten (1923) demonstrated that the ratio of the diameter of the scales of Lake Huron whitefish to the length of fish was nearly constant. A similar body-scale relationship has been demonstrated for the related lake herring *(Coregonus artedi)* by Van Oosten (1929) and by Smith (1956). Largely on the basis of Van Oosten's findings (1923, 1929) most investigators working on coregonids have employed the direct-proportion method for the calculation of growth. The body-scale relationship was, nevertheless, determined for the Munising Bay whitefish stock. "Key" scales were not available, but because the scale samples were taken from a key area, it was felt that average scale diameters based on the measurements of three (sometimes two) scales from each fish would be a reliable substitute for key-scale measurements in the determination of body-scale relationship.

All whitefish captured in June and August, from which scales were collected, were employed for the determination of the body-scale relationship (Table 7). Since a plot of average fish length and scale diameters for 0.5-inch groupings of fish indicated the body-scale relation to be linear, a straight line was

fitted to the data by least squares (Figure 2). The equation of the line is:

$$L = 1.486 + 1.222\,S,$$

where L = the total length of the fish (inches), S = the scale diameter (magnified) in inches, and 1.486 is the intercept. Since this value of the intercept differs significantly from zero, it is concluded that the body-scale ratio is not constant in the Munising Bay whitefish population.

The growth in length of the whitefish was calculated by the formula

$$Ln = 1.5 + \frac{Lt - 1.5}{St} Sn$$

where Ln equals the length of the fish at the end of the n^{th} year of life, Sn equals the diameter of the scale within the n^{th} annulus, Lt equals the total length of the fish at capture, St equals the total diameter of the scale, and 1.5 is the intercept rounded to the nearest 0.1 inch.

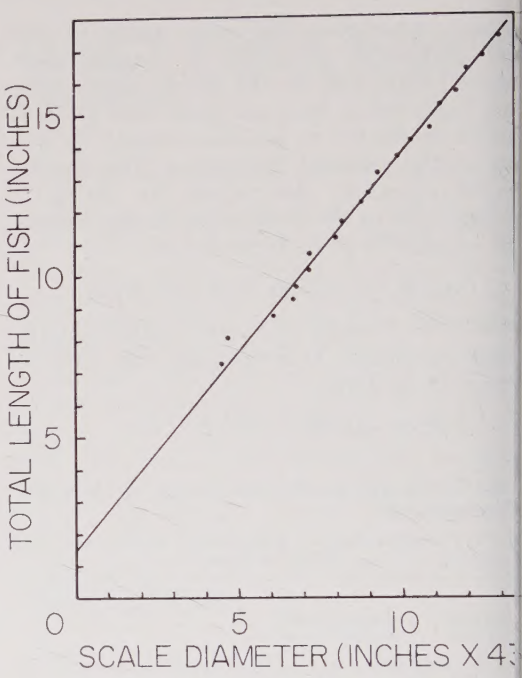

FIGURE 2.—Relation between total length of fi and magnified diameter of scales of Munising B whitefish.

CALCULATED GROWTH IN LENGTH

The average calculated lengths of males and females in different age groups of whitefish gave no evidence of sex differences in the growth rate. Data for males and females therefore were combined (Table 8). The agreement among the calculated growth histories of the different age groups was very close, particularly in view of the small number of fish in several groups and th great difficulty with which the scales we read. No clear trends are to be seen toward systematic change of calculated lengths wit increase of age, and discrepancies that do o cur probably can be attributed to sma samples or annual fluctuations of growt Especially reassuring is the agreement b tween length at capture (the last length f each age group) and the calculated lengt for the same year of life as determined measurements of scales of fish of greater ag The data of Table 8 appear to justify ful the conclusions that (1) the samples of t age groups were little biased by gear sele tion or other selective influence, (2) estimat of growth were little affected by the rejectio of numerous fish that had unreadable scale and (3) the empirically determined bod scale relation was highly satisfactory for t calculation of growth.

TABLE 7.—*Relation between total length of fish and magnified scale diameter of Munising Bay whitefish*

[Scales were taken from a key area; scale diameter in inches x 43]

Length interval (inches)	Number of fish	Average length (inches)	Average magnified scale diameter
7.0- 7.4	2	7.3	4.5
7.5- 7.9	1	7.5	5.9
8.0- 8.4	2	8.1	4.7
8.5- 8.9	3	8.8	6.1
9.0- 9.4	8	9.3	6.7
9.5- 9.9	17	9.7	6.8
10.0-10.4	27	10.2	7.2
10.5-10.9	28	10.7	7.2
11.0-11.4	37	11.2	8.0
11.5-11.9	23	11.7	8.2
12.0-12.4	24	12.3	8.8
12.5-12.9	28	12.6	9.0
13.0-13.4	16	13.2	9.3
13.5-13.9	10	13.7	9.9
14.0-14.4	11	14.2	10.3
14.5-14.9	3	14.6	10.9
15.0-15.4	5	15.3	11.2
15.5-15.9	3	15.7	11.7
16.0-16.4	1	16.4	12.0
16.5-16.9	2	16.8	12.5
17.0-17.4	1	17.4	13.0

The estimates of the general growth i length at the bottom of Table 8 are based c the grand average calculated lengths and c the successive summation of the grand ave age increments of calculated length. Bot procedures are basically valid and for th Munising Bay fish they give closely simil

TABLE 8.—*Calculated total length at end of each year of life of each age group of Munising Bay whitefish and average growth for the combined age groups*

[The last calculated length for each age group is actually the average length at capture in June, as the current season's growth had not begun]

Age group	Number of fish	Length (inches) at end of year															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
II	2	4.5	7.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
III	5	5.6	7.2	8.5	—	—	—	—	—	—	—	—	—	—	—	—	—
IV	17	5.5	7.5	8.7	9.9	—	—	—	—	—	—	—	—	—	—	—	—
V	19	5.5	7.1	8.7	9.7	10.4	—	—	—	—	—	—	—	—	—	—	—
VI	31	5.5	7.3	8.5	9.4	10.2	11.0	—	—	—	—	—	—	—	—	—	—
VII	37	5.7	7.5	8.7	9.5	10.2	10.9	11.4	—	—	—	—	—	—	—	—	—
VIII	22	5.5	7.1	8.2	9.2	10.0	10.7	11.3	11.9	—	—	—	—	—	—	—	—
IX	16	5.5	7.1	8.2	9.2	10.0	10.9	11.6	12.2	12.8	—	—	—	—	—	—	—
X	15	5.2	6.7	7.9	8.9	9.8	10.6	11.3	12.0	12.7	13.4	—	—	—	—	—	—
XI	7	5.0	6.8	8.1	9.1	9.9	10.7	11.6	12.3	12.9	13.4	14.0	—	—	—	—	—
XII	4	5.4	6.7	8.2	9.0	9.9	10.9	12.0	13.0	13.7	14.4	15.0	15.5	—	—	—	—
XIII	2	5.4	6.9	8.4	9.5	10.4	11.6	12.3	12.9	13.6	14.3	14.9	15.4	15.8	—	—	—
XVI	1	5.0	6.3	7.9	8.8	9.6	10.2	11.1	12.0	12.6	13.2	14.5	15.2	15.5	16.0	16.3	16.7
Grand average calculated length		5.5	7.2	8.4	9.4	10.1	10.8	11.5	12.1	12.9	13.6	14.4	15.4	15.7	16.0	16.3	16.7
Increment of average		5.5	1.7	1.2	1.0	0.7	0.7	0.7	0.6	0.8	0.7	0.8	1.0	0.3	0.3	0.3	0.4
Grand average increment of length		5.5	1.7	1.2	1.0	0.8	0.8	0.7	0.6	0.6	0.6	0.7	0.5	0.3	0.5	0.3	0.4
Sum of average increment		5.5	7.2	8.4	9.4	10.2	11.0	11.7	12.3	12.9	13.5	14.2	14.7	15.0	15.5	15.8	16.2

results. The estimate based on the sum of the average increments, however, is preferred (Figure 3). The curve derived from average increments has the advantage of greater smoothness, particularly in the later years of life that are represented by few fish.

The growth of Munising Bay whitefish is similar to that of many coregonids in that the annual increment was by a large margin the greatest in the first year of life and thereafter followed a general (though not perfectly regular) downward trend. The increments beyond the first year were very low. Second-year growth amounted to only 1.7 inches and no annual increment exceeded 1.0 inch after the third year or 0.5 inch after the eleventh. As a result of this slow growth, Munising Bay whitefish required almost 5 years to reach a length of 10 inches and a full 13 years to reach 15 inches. The highest calculated length attained (16.2 inches in 16 years) was still 0.8 inch below the Michigan legal minimum length of 17 inches. Exploitation of the Munising Bay stock under the present size limit would not be a rewarding operation.

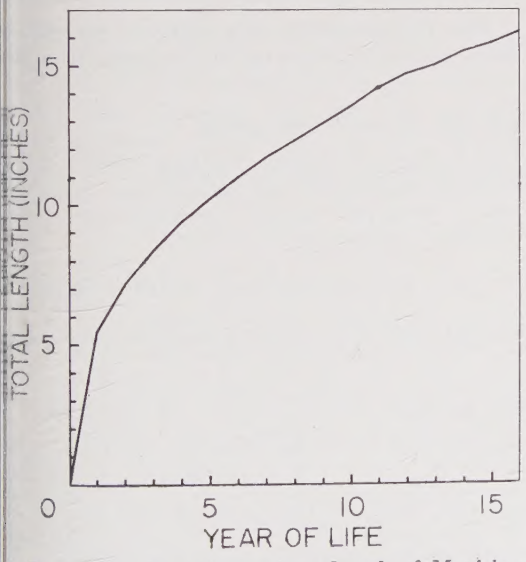

FIGURE 3.—General growth in length of Munising Bay whitefish.

CALCULATED GROWTH IN WEIGHT

Calculated growth in weight (Table 9) was determined by applying calculated

TABLE 9.—*Calculated weights at the end of each year of life of Munising Bay whitefish*

[Weights are from the general length-weight relation and correspond to lengths at the end of year of life on the general growth curve]

Year of life	Calculated weight	Increment	Year of life	Calculated weight	Increment
1	0.6	0.6	9	9.2	1.3
2	1.5	0.9	10	10.6	1.4
3	2.4	0.9	11	12.4	1.8
4	3.3	0.9	12	13.9	1.5
5	4.3	1.0	13	14.8	0.9
6	5.6	1.3	14	16.4	1.6
7	6.7	1.1	15	17.4	1.0
8	7.9	1.2	16	18.9	1.5

lengths (sum of the average increments of length) of Table 8 to the length-weight relation. The annual increments of weight increased irregularly through the first 11 or 12 years and thereafter fluctuated without trend. Increments in individual years of life were small (0.6 ounce in the first year of life to a maximum of 1.8 ounces in the 11th year of life). Because of this slow growth in weight, considerable time was required for the fish to reach even a moderate size. Slightly more than 8 years were needed for fish to reach a weight of 8 ounces and a little less than 14 years to reach 1 pound.

COMPARISON OF THE GROWTH OF WHITEFISH IN MUNISING BAY WITH GROWTH IN OTHER WATERS

In order to compare the growth of whitefish from a number of localities (Table 10), the data from various sources have been adapted to permit presentation in terms of total length in inches. A full coverage of published data has not been attempted. All available records for the Great Lakes have been included, but data for other waters have been limited to two inland lakes that have stocks with extremely slow growth.

Growth of the Munising Bay whitefish in the first year of life does not differ greatly from the first-year growth in the other Great Lakes whitefish populations, and the length at the end of 2 years was very similar in Munising Bay and in the Fox Islands area of Lake Michigan. In all other comparisons, however, the Munising Bay whitefish were decidedly shorter than fish of the same age other Great Lakes stocks. In general, the di ferences increased with age. Munising Ba fish after 4 years were 2.6 to 8.7 inch shorter than whitefish in other Great Lak waters and in 12 years were 8.8 to 11.2 inch shorter (Lake Michigan not represented the higher age).

Whitefish from two small inland lakes, the contrary, had growth rates similar to below that of the Munising Bay stock. Whit fish from Trout Lake, Wisconsin, (Hile a Deason, 1934) were shorter than Munisi Bay fish in the first 4 years of life, but we longer in the sixth and later years (fifth-ye lengths were identical in the two stocks Slowest growth yet reported for any pop lation is that of a stock of dwarf whitefi discovered by Kennedy (1943) in La Opeongo. These dwarf whitefish (Opeon also contains a stock with more rapid growt reached a length of 6.0 inches in 5 years compared with 10.1 inches in Munising Bay

SEX RATIO

Although the sex ratio of the Munisi Bay whitefish fluctuated widely among the a groups (Table 11), the belief that the da were without trend was supported by a st tistical test. Much of the variation probab was a result of the small numbers of fish several of the age groups. In the enti sample, all ages combined, the sexes were a most equally represented (52 percent males

The failure of the sex ratio of Munisi Bay whitefish to change systematically wi

TABLE 10.—*Growth in length of whitefish in Munising Bay and in certain other waters*

[Sources of data: Lake Erie, Van Oosten and Hile (1949); Lake Huron, adapted from Van Oosten (1939); Lake Ontario, adapted from Hart (1931); Lake Michigan, Roelofs (1957); Lake Opeongo (dwarf race), adapted from Kennedy (1943); Trout Lake, adapted from Hile and Deason (1934)]

Area	Average calculated total length (inches) at end of year of life															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1
Great Lakes																
Lake Erie	6.9	12.7	16.1	18.1	19.6	20.7	21.4	22.1	22.8	23.2	23.7	24.2	24.6	25.0	25.3	25
Lake Huron[1]	5.0	8.9	12.3	16.1	19.2	21.4	22.9	23.9	24.8	25.3	25.9	26.6	—	—	—	—
Lake Michigan																
Big Bay de Noc	5.6	9.4	13.8	17.9	—	—	—	—	—	—	—	—	—	—	—	—
South Fox Island	4.3	7.0	9.9	13.2	—	—	—	—	—	—	—	—	—	—	—	—
Lake Ontario[1, 2]	—	—	9.4	12.0	15.4	17.9	19.1	20.4	21.0	22.3	—	25.8	—	—	—	—
Lake Superior																
Munising Bay	5.5	7.2	8.4	9.4	10.1	10.8	11.5	12.1	12.9	13.6	14.4	15.4	15.7	16.0	16.3	16
Small inland lakes																
Lake Opeongo[3]	4.4	5.3	5.6	5.8	6.0	—	—	—	—	—	—	—	—	—	—	—
Trout Lake[3]	3.8	5.5	7.1	8.5	9.7	10.8	11.9	12.9	14.3	15.0	15.7	16.2	16.8	17.2	—	—

[1]Lengths taken directly from a table in Van Oosten and Hile (1949). Methods of adaptation are described by them.
[2]Actual lengths at capture during growing season subsequent to indicated year.
[3]Standard lengths converted to total lengths by means of a factor determined by Hile and Deason (1934).

TABLE 11.—*Sex composition of age groups of Munising Bay whitefish*

Age group	Number of males	Number of females	Percentage males
II	2	—	100
III	—	5	0
IV	11	6	65
V	12	7	63
VI	15	16	48
VII	21	16	57
VIII	11	11	50
IX	6	10	38
X	8	7	53
XI	5	2	71
XII	1	3	25
XIII	—	2	0
XVI	1	—	100
Total	93	85	52

crease of age is in contrast to the findings in o other Great Lakes stocks. The percentage f male whitefish in samples from Lakes uron (Van Oosten, 1939) and Erie (Van osten and Hile, 1949) decreased with an in- ease in age. A decision as to whether this isagreement between the Munising Bay white- sh and the Lake Huron and Lake Erie stocks epresents true differences in the biological haracteristics of the stocks is reserved be- ause of problems of segregation, biased ampling, and (in exploited stocks) differen- ial exploitation. Indeed the whole question of he accurate determination of the sex ratio nd of factors that influence the ratio is too omplex to be discussed in this paper. An ex- ellent review of the matter may be found, owever, in a recent paper by Alm (1959).

MATURITY

The June and August samples of Munising Bay whitefish exhibited such closely similar rends in the relation between length and ma- urity that the data for the two groups were combined (Table 12). All fish shorter han 11.5 inches were immature. The mallest mature males appeared in the 11.5- to 11.9-inch length interval. Fifty percent of the males were mature at 13.0-13.4 inches and all males (11 fish) longer than 14.4 inches were mature. The first mature females appeared at 12.0-12.4 inches, somewhat fewer than half were mature at 13.5-14.9 inches, and all fish longer than 14.9 inches (7 individuals) were mature. First maturity and 100-percent maturity of males occurred at lengths 0.5 inch shorter than in females.

Whitefish attain maturity at much shorter lengths in Munising Bay than in Lake Huron where Van Oosten (1939) reported first maturity for males at 17.8 inches and of females at 18.3 inches, and 100-percent maturity for males at 20.1 inches and females at 21.5 inches. First maturity was attained in Great Slave Lake at a small size (20 percent mature at an average fork length of 12.1 inches) but average length at 100-percent maturity was 18.0 inches (Kennedy, 1953). Smallest mature whitefish yet reported were from Lake Opeongo where Kennedy (1943) found that the first dwarf whitefish (both males and females) were mature at a standard length of 4.3-4.5 inches.

The slow growth of Munising Bay whitefish in later years of life caused the small differences between the sexes in length at attainment of maturity (Table 12) to become large when the comparison is on the basis of age (Table 13). No female younger than the X group was mature whereas 14 to 50 percent of the males were mature in age-groups VII-IX. All fish of both sexes were mature, however, in the XII age group and older.

The age at first attainment of maturity is much greater in Munising Bay whitefish than in Lake Huron, Lake Erie, and Great Slave Lake stocks. In Lakes Huron (Van Oosten, 1939) and Erie (Van Oosten and Hile, 1949) the first mature whitefish were found in age-groups III and II respectively. The Great

TABLE 12.—*Relation between length and sexual maturity of Munising Bay whitefish*

[All fish shorter than 11.5 inches were immature; all fish longer than 14.9 inches were mature]

Length interval (inches)	Male			Female		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage mature
11.5-11.9	15	5	25	21	—	0
12.0-12.4	25	6	19	23	4	15
12.5-12.9	20	8	29	15	2	12
13.0-13.4	9	9	50	14	4	22
13.5-13.9	9	9	50	7	5	42
14.0-14.4	1	7	88	5	3	38
14.5-14.9	—	2	100	3	2	40

TABLE 13.—*Relation between age and sexual maturity of Munising Bay whitefish*

[In parentheses, number of mature fish at left and immature at right; all fish younger than age-group VII were immature and all in age groups older than XI were mature]

Age group	Percentage mature	
	Males	Females
VII	14.3 (3-18)	0.0 (16-0)
VIII	27.3 (3-8)	0.0 (11-0)
IX	50.0 (3-3)	0.0 (10-0)
X	37.5 (5-3)	42.9 (4-3)
XI	60.0 (2-3)	50.0 (1-1)

Slave Lake whitefish (Kennedy, 1953) achieved first maturity in age-group IV. The dwarf whitefish from Lake Opeongo achieved first maturity in age-group II.

The more rapidly growing members of the Munising Bay whitefish stock mature earlier than the slow-growing individuals. The mature fish were longer in six of seven comparisons between the mean lengths of mature and immature fish of the same age and sex (Table 14); the X-group females were the single exception. This finding is in agreement with observations on the relation between growth rate and attainment of maturity in numerous populations (Alm, 1959).

TABLE 14.—*Relation between the average length of immature and mature Munising Bay whitefish of the same age*

[All fish in age-group VI and younger were immature; all fish in age-group XII and older were mature]

Age group	Male		Female	
	Immature	Mature	Immature	Mature
VII	11.5	12.5	—	—
VIII	11.8	12.3	—	—
IX	12.9	14.6	—	—
X	12.8	14.2	13.5	12.9
XI	12.5	14.0	14.2	15.5

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Standing Crops of Fishes in Kentucky Farm Ponds[1]

William R. Turner
Kentucky Department of Fish and Wildlife Resources
Frankfort, Kentucky

ABSTRACT

Estimates of standing crops of fishes in 22 Kentucky farm ponds were made during the summers of 1956, 1957, and 1958. The studies were essentially limited to ponds containing populations of largemouth bass *(Micropterus salmoides)*, bluegill *(Lepomis macrochirus)*, and/or green sunfish *(Lepomis cyanellus)*. Prior to treatment with rotenone, fish were captured by seining, fin-clipped, and returned to the pond. The total standing crops were calculated from the percentages of fin-clipped fish recovered following the total eradication of each fish population. Standing crops of fish in the 22 ponds ranged from 73 to 770, and averaged 385 pounds per acre. Nine ponds contained balanced, while 13 contained unbalanced fish populations. *F/C* ratios in the balanced populations ranged from 1.6 to 8.0, and averaged 4.6, while in the unbalanced populations they ranged from 4.1 to 37.7, and averaged 16.6. In the nine ponds containing balanced populations there was an average standing crop of 282 pounds of fish per acre, and 48 percent (130 pounds per acre) of that weight was composed of harvestable-sized fish. In the 13 ponds containing unbalanced fish populations there was an average standing crop of 456 pounds per acre, of which only 15 percent (70 pounds per acre) was composed of harvestable-sized fish. There was a relatively high positive correlation between the size of the standing crops and the total alkalinities in the ponds ($r = 0.67$). There was a positive correlation between the size of the standing crops and the amounts of potassium ($r = 0.44$) and phosphorus ($r = 0.72$) present in the soils of the watersheds.

Estimates were made of the standing crops of fishes in 22 unfertilized Kentucky farm ponds during the summer months from June 1956 through September 1958. The studies were limited to ponds containing populations composed of largemouth bass *(Micropterus salmoides)*, bluegill *(Lepomis macrochirus)*, and/or green sunfish *(Lepomis cyanellus)*, in order to obtain data applicable to the stocking methods employed by the Kentucky Department of Fish and Wildlife Resources. The study techniques reported here are those that ultimately provided the most satisfactory results.

Experimental ponds were selected from a group of ponds in which the fish population had been previously investigated by Hall (1958). Selection in this manner provided considerable assurance that the desired species were present in each pond, since they had been stocked by personnel of that project and were test-seined each successive year.

Ponds containing balanced fish populations were obtained for experimental purposes by paying the pond owner the sum of $50 in exchange for study privileges; while the owners of ponds containing unbalanced fish populations were recipients of free reclamation services. In the present paper the terminology applying to the relationships between balanced and unbalanced fish populations follows that outlined by Swingle (1950). In general, a balanced population is one that provides sustained yields of fishes of a size desirable to the angler, whereas an unbalanced population does not.

After the status of the fish population had been determined by test-seining, each pond was mapped and the surface area computed. The 22 ponds selected for the study ranged in size from 0.45 to 1.56 acres, and had an average surface area of 0.96 acre. Physicochemical characteristics of the waters were determined in each pond. Water samples were collected from all ponds between 8:00 and 10:30 a.m. and total alkalinity, temperature, and pH were recorded. Soil samples were collected from the watershed of each pond with a sampling tube and were later analyzed for available potassium, available phosphorus, and pH.

Fish were captured for marking by making several hauls with a ½-inch mesh, 60- by 12-foot seine. Each fish was marked by excising a small portion of the lower lobe of the caudal fin, and released. Just enough of the fin was removed to leave a distinguishable

[1]This study was conducted by the Kentucky Department of Fish and Wildlife Resources in conjunction with Federal Aid in Fisheries, Dingell-Johnson Project F-10-R.

mark but not enough to impede locomotion greatly. At least 100 fish were marked for each acre of water surface. After the fish were marked, all those showing signs of distress were removed from the pond and their numbers deducted from the marking records.

After allowing from 2 to 4 days for the marked individuals to mix with the rest of the population, the entire pond was treated with an emulsifiable rotenone formulation at a concentration of 1 p.p.m. For 3 days following treatment with rotenone, all fishes that could be recovered were measured and weighed. Representative weights taken from fishes recovered the first day were applied to fish recovered on succeeding days, since it has been shown by Krumholz (1950) and Larimore (1952) that the weights of fishes may change drastically after death. The average number of marked fish recovered from the 22 ponds for the 3-day period was 73 percent; the first day recovery averaged 20 percent, the second day, 44 percent, and the third day, 9 percent. The standing crop of each pond was calculated by multiplying the weight of fish recovered by the appropriate factor determined from the percentage of marked fish recovered.

In order to simplify presentation, each pond is designated by a code number, such as B-2. The letter represents the soil region in which the pond is located, and the number indicates the sequence of study within that particular region. Hence, B-2 was the second pond studied in the Bluegrass region.

The 22 study ponds were distributed among the six major soil regions of the State as follows: Jackson Purchase (JP), 1; Pennyroyal (P), 6; Western Coalfields (WC), 3; Outer Bluegrass (OB), 9; Bluegrass (B), 2; and Eastern Coalfields (EC), 1. The prefix denoting these specific soil regions has been retained so that some conception of the natural fertility of these diverse areas may be realized. An inadequate number of studies in some of these regions, however, makes such a comparison impractical.

STANDING CROPS OF BALANCED AND UNBALANCED FISH POPULATIONS

The average standing crop in the 22 study ponds was 385 pounds per acre, ranging from 73 pounds per acre in pond JP-1 to 770 pounds per acre in pond OB-5. Nine of the study ponds contained balanced fish populations while 13 contained unbalanced populations. The standing crops in the nine ponds containing balanced fish populations (Table 1) ranged from 73 to 670 pounds of fish per acre, with an average of 282 pounds per acre. The ponds had been stocked 3½ to 9½ years prior to the study and the average time since stocking was 5 years. The 13 ponds containing unbalanced fish populations had been stocked from 2½ to 7½ years before the study began, and the average time since the original stocking was 4½ years. The average standing crop of fish in these ponds was 456 pounds per acre (Table 2), and ranged from 157 to 770 pounds per acre.

Ball (1948) reported an increase in standing crop with increased alkalinity in Michigan lakes. Carlander (1955) found a similar

TABLE 1.—*Analyses of water and soil samples from nine ponds containing balanced fish populations*

Pond	Water analyses					Soil analyses				
	Standing crop of fish (pounds/acre)	Maximum depth (feet)	Total alkalinity (p.p.m.)	pH	Sampling date	Watershed	pH	Available potassium[1] (pounds/acre)	Available phosphorus[2] (pounds/acre)	Limestone particles
JP-1	73	9	12	6.8	July 9, 1958	Pasture-woodlot	5.0	120	9	None
WC-1	124	11	39	7.7	June 25, 1956	Pasture-woodlot	5.4	221	76	None
P-5	444	5	49	7.8	Aug. 30, 1956	Pasture-barnyard	5.8	373	300+	Few
P-7	516	5	21	8.1	Aug. 20, 1958	Pasture-barnyard	5.8	89	54	None
P-8	157	13	30	7.8	Sept. 3, 1958	Cultivated	5.1	120	6	None
OB-2	670	9	69	7.6	Oct. 1, 1956	Pasture	5.4	144	165	None
OB-9	122	12	38	7.3	July 23, 1958	Pasture-woodlot	6.0	133	30	Few
OB-10	291	14	73	7.2	Aug. 1, 1958	Pasture	5.5	155	96	None
EC-1	137	12	17	7.3	June 18, 1958	Pasture-woods	5.0	91	3	None

[1]Potassium ratings—low, under 125; medium, 126 to 200; high, above 200.
[2]Phosphorus ratings—low, under 25; medium, 26 to 50; high, above 50.

TABLE 2.—*Analyses of water and soil samples from 13 ponds containing unbalanced fish populations*

Pond	Water analyses					Soil analyses				
	Standing crop of fish (pounds/acre)	Maximum depth (feet)	Total alkalinity (p.p.m.)	pH	Sampling date	Watershed	pH	Available potassium[1] (pounds/acre)	Available phosphorus[1] (pounds/acre)	Limestone particles
WC-2	545	9	52	7.8	Aug. 8, 1957	Pasture	5.6	420	69	None
WC-3	343	9	48	6.8	Aug. 15, 1957	Pasture-woodlot	5.8	71	15	None
P-1	315	6	30	7.0	July 27, 1956	Pasture	4.9	209	6	None
P-2	347	3	37	7.4	Aug. 2, 1956	Pasture	5.6	428	45	None
P-3	328	5	49	7.5	Aug. 9, 1956	Pasture	6.2	233	187+	Numerous
OB-3	416	9	50	7.2	July 5, 1957	Pasture	5.8	93	300+	None
OB-4	685	14	103	8.3	July 11, 1957	Pasture	6.0	178	270	Few
OB-5	770	9	65	8.6	July 18, 1957	Pasture-cultivated	6.6	575	300+	Numerous
OB-6	242	9	39	8.6	July 25, 1957	Woodlot	5.2	102	27	None
OB-7	482	7	76	7.9	Aug. 23, 1957	Pasture	6.3	115	300+	Few
OB-8	157	8	72	9.0	Oct. 28, 1957	Lawn-woodlot	5.5	115	9	None
B-1	664	6	87	8.3	June 12, 1957	Pasture	6.8	253	300+	Numerous
B-2	632	10	96	7.3	June 19, 1957	Pasture	6.4	180	189	Few

[1]Available potassium and phosphorus ratings are given in Table 1, footnotes 1 and 2.

relationship in warm-water lakes, with a coefficient of correlation, $r = 0.64$. In 26 Oklahoma ponds, Jenkins (1958) reported a somewhat lower degree of correlation ($r = 0.37$) between standing crops and alkalinities. There was also a positive relationship between the standing crops of fish and the total alkalinities in the 22 Kentucky ponds, with a relatively high correlation, $r = 0.67$. Total alkalinities in these ponds ranged from 12 to 103 p.p.m. (Tables 1 and 2).

In general, the standing crops of fishes in the 22 ponds of the present study were reflected by the fertility of the soils in the watershed. There was a high positive correlation ($r = 0.72$) between the amounts of available phosphorus in the soils of the watersheds and the total standing crops in the ponds. Ponds in woodland drainage areas usually supported standing crops that were lower than average (385 pounds per acre), and without exception, the more productive ponds were located in fields utilized for pasture. Correspondingly, there were significantly lower amounts of available phosphorus in the woodland drainages because most phosphorus compounds are "bound" by higher plants. The chief compounds of phosphorus are supplied by organic decomposition and are most frequently encountered in soils receiving barnyard drainage and those used as pasture. On such watersheds the elements in manures that are essential to fertility are readily available through leaching.

There was also a positive relationship between the amounts of available potassium in the soils of the watersheds and the total standing crops in the 22 ponds, but with a comparatively less significant degree of correlation ($r = 0.44$) than that between available phosphorus and standing crops.

DYNAMICS OF BALANCED AND UNBALANCED POPULATIONS

The average standing crop of largemouth bass was 43 pounds per acre, and ranged from 11 to 86 pounds per acre in the 22 ponds. The average standing crop of bluegills was 365 pounds per acre, and ranged from 45 to 749 pounds per acre in the 22 ponds. Bluegills tended to dominate the population in all ponds in which they occurred and had average E values of 75 in the balanced populations and 87 in the unbalanced populations (Table 3).

In the nine balanced populations there was an average standing crop of 224 pounds of bluegills per acre, and 42 percent (95 pounds per acre) of that weight was composed of harvestable-sized fish. In 12 ponds containing unbalanced populations there was an average standing crop of 410 pounds of bluegills per acre, but only 12 percent (48 pounds per acre) of the total was made up of harvestable-sized fish. Although the average total bluegill crop of the unbalanced populations was nearly double that in the balanced populations, the opposite was true with respect to harvestable-sized fish. This relationship indicates the stunted condition of the individuals in the unbalanced populations.

The average standing crop of largemouth

TABLE 3.—*Species occurrence, standing fish crops, harvestable crops, and various ratios in balanced and unbalanced fish populations in 22 Kentucky farm ponds, 1956-1958*

Species	Occurrence (number of ponds)	Average standing crop (pounds/acre)	Harvestable fish (pounds/acre)	Average A_t value	Average E value
Balanced populations (9 ponds)					
Largemouth bass	9	49	33	67	21
Bluegill	9	224	95	42	75
Longear sunfish	1	13	0	0	8
Green sunfish	1	28	4	14	4
White crappie	3	6	3	53	3
Channel catfish	1	5	5	100	4
Yellow bullhead	1	10	7	67	1
White sucker	1	t*	0	0	t**
Unbalanced populations (13 ponds)					
Largemouth bass	9	37	29	79	9
Bluegill	12	410	48	12	87
Green sunfish	9	69	3	5	17
White crappie	2	3	1	54	1
Bullheads	4	7	5	76	2
White sucker	1	13	11	84	2
Goldfish	2	5	5	100	1

*t = less than 0.6 pound per acre.
**t = less than 0.6 percent.

bass in the nine balanced populations was 49 pounds per acre, with 67 percent (33 pounds per acre) being composed of harvestable-sized fish. In nine ponds containing unbalanced populations, there was an average standing crop of 37 pounds of largemouth bass per acre, of which 79 percent (29 pounds per acre) was composed of harvestable-sized fish. The relatively higher percentage of the bass crop composed of harvestable-sized fish in the unbalanced populations was usually represented by a small number of large individuals and few or no young fish.

In general, the ponds containing unbalanced fish populations were overcrowded with forage species. The average F/C ratio of the 13 unbalanced populations was 16.6 and ranged from 4.1 to 37.7; while the average F/C ratio of the nine balanced populations was 4.6 and ranged from 1.6 to 8.0. There was some overlapping of F/C ratios of balanced and unbalanced populations in the 4.1 to 7.3 range, but the A_t values of the unbalanced populations were considerably lower in such instances. An average of 48 percent (A_t value) of the total standing crop was composed of fish of harvestable size in the balanced populations, while in the unbalanced populations an average of only 15 percent of the fishes attained a size desirable to the angler.

Other species listed in Table 3, excepting green sunfish, were incidental to the study and were represented by a few individuals in an insignificant number of ponds. Green sunfish occurred in nine unbalanced populations and constituted an average standing crop of 69 pounds per acre. Only 5 percent (3 pounds per acre) of that weight was composed of harvestable-sized fish. This species also occurred in one balanced population in which it represented 14 percent (4 pounds per acre) of the harvestable-sized fish.

Estimates of the standing crop of fish in 22 Kentucky farm ponds, originally stocked with largemouth bass and bluegill, disclosed an average standing crop of 385 pounds per acre, which compares favorably with similar studies conducted on warm-water ponds in other sections of the country. Generally, ponds located within the limestone areas of the state (Bluegrass, Outer Bluegrass, and Pennyroyal) contained higher standing crops than those in the mountainous sandstone regions of eastern Kentucky and the predominantly shaly-sandstone areas of the Western Coalfields from which limited samples were obtained (four ponds). An estimate of standing crops, however, cannot be inferred from the location of a pond in any particular soils region, because there is a great diversity in these regions. The standing crop of pond WC-2, for example, was 545 pounds per acre or considerably higher than some of those located in relatively fertile areas.

The fertility of the immediate watershed was found to be a pertinent factor relating to pond productivity. Ponds located in pastures receive a considerable amount of indirect fertilization from livestock and were usually more productive than those in wood-

land drainages. Artificial fertilization, employing compounds which would increase the phosphate and carbonate content, is recommended for ponds located in woodland drainage areas and in other areas where these elements are not supplied naturally.

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Distribution of Menhaden, Genus *Brevoortia*, in the Gulf of Mexico[1]

J. Y. Christmas and Gordon Gunter
Gulf Coast Research Laboratory, Ocean Springs, Mississippi

ABSTRACT

There are three menhaden in the Gulf of Mexico. *Brevoortia patronus* ranges around the northern Gulf from Brazos Santiago, Texas, to Tampa Bay, Florida, and supports a large commercial fishery centered in the area of greatest abundance, the Louisiana coast. The fish grows up in estuarine areas and ranges into fresh water at smaller sizes. It ranges into pure sea water and as far offshore as 25 miles. The greatest depth at which it has been taken is 20 fathoms. *Brevoortia gunteri* and *B. smithi* are fine-scaled species that live in the western and eastern Gulf, respectively. (The latter species is also found in the Atlantic.) Both enter fresh waters at small sizes. The greatest depth at which they have been taken is 8 fathoms, and the offshore salinity limit is unknown. The known range of *B. gunteri* extends from Chandeleur Sound, east of the Mississippi River, around the shores of the western Gulf to Campeche, Mexico. It is not often caught in the eastern part of its range, and the greatest abundance seems to be in the western Gulf. The known range of *B. smithi* is extended from Cedar Keys, Florida, to Chandeleur Sound, Louisiana, where all three species of Gulf menhaden come together. *B. smithi* ranges also southward to the Caloosahatchee River, Florida. *Brevoortia gunteri* and *B. patronus* have been recorded in the Laguna Madre of Texas at salinities of 60 *per mille*. *Brevoortia gunteri* and *B. smithi* apparently grow to considerably larger size than *B. patronus*, but they are much less abundant and are not important in the commercial fishery.

INTRODUCTION

The menhaden fishery of the Gulf and Atlantic coasts of the United States exceeded 2 billion pounds production in 1956 and 1959. It is the only fishery in North America that ever yielded such a high catch. Menhaden are also of general ecological importance because of their vast numbers. Several years before the Gulf menhaden fishery approached present production levels, *Brevoortia patronus* Goode was ranked among the three most abundant fishes of large species mass in the northern Gulf waters (Gunter, 1941). The present account summarizes records on the distribution of menhaden in the Gulf of Mexico and gives certain new information.

Brevoortia patronus Goode, 1878

Goode (1879) stated that the first Gulf menhaden received by the National Museum were collected in west Florida in 1864, and he quoted a lighthouse keeper who had seen vast quantities of the fish in the Matagorda Bay (Texas) region in 1872. Before the above account was published Goode (1878) described the common Gulf species, *Brevoortia patronus*. The valid part of his description (see *B. gunteri* below) was base on specimens from Brazos Santiago, Texas at the southern end of the Laguna Madre near the Mexican border, which remain th southwesternmost known.

Hildebrand (1948) stated that no spec mens of *B. patronus* were available from eas or south of Apalachicola in the eastern Gul but he called attention to the record c Henshall (1894) from Tampa. Henshall's rec ord is questionable because it could hav involved *B. smithi*, now known from tha area. Briggs (1958) seems to have accepte Henshall's record, for he gave the souther range of *B. patronus* on the Florida coas as Tampa. The listing of *B. patronus* amon the fishes washed up on the beach at For Myers Beach, Florida, after a red tide i 1947 (Gunter *et al.*, 1948), was also possibl erroneous. Until quite recently, there was n dependable record of *B. patronus* south o Cedar Keys in the eastern Gulf. Suttku (1958) examined two specimens from Ceda Keys. Springer and Woodburn (1960) re ported several specimens of *B. patronus* fron the Tampa Bay area, the largest one o which was 135 millimeters in standard length Gunter and Gordon E. Hall have recentl taken young fish from the Caloosahatche River, extending the known range southward about 30 miles.

[1]This work was carried out in connection with Contract No. 14-19-008-9335, Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service.

Various workers have shown that *B. patronus* is quite common in inshore waters, both in the bays and shallow Gulf. Gunter (1936, 1938a, b), Suttkus (1956), and Gunter and Shell (1958) have indicated considerable abundance of *B. patronus* in shallow Louisiana waters; Reid (1955a, b; 1956, 1957) and Simmons (1957) have given similar information for Texas waters. These observations also demonstrate that young menhaden are raised in the bays, sometimes in waters of very low salinities. Gunter and Shell took small *B. patronus* in Grand Lake, Louisiana, where the salinity varied from 0.10 to 0.19 parts per thousand, a level which is considered to be in the fresh-water range. Gunter (1956) and Briggs (1958) listed *B. patronus* as euryhaline.

The common Gulf menhaden is a shallow-water fish, but information on its offshore range is limited. Hildebrand (1954) wrote that shrimp trawlers sometimes encountered menhaden in such numbers that the trawls burst from weight of the fish. He took 14 *B. patronus* in one trawl haul at 17 fathoms off St. Joseph Island, Texas, and one fish at 3 fathoms off Corpus Christi Pass. Salinities were not determined but presumably the fish were in pure sea water. Simmons (1957) noted that *B. patronus* was commonly taken in waters of salinity up to 60 parts per thousand in the hypersaline Laguna Madre of Texas. There are, however, no published records of salinity determinations in the open Gulf to prove that *B. patronus* enters undiluted sea water. Christmas, Gunter, and Whatley[2] recorded salinities at 87 sets of menhaden purse seiners, mostly in Louisiana around the mouth of the Mississippi River, with a few in Mississippi and Alabama waters. Seventy percent of the 2 million pounds of menhaden caught were in waters ranging from 5 to 24 parts per thousand; the highest salinity recorded for any catch was 31.6.

On January 7, 1959, the senior author caught one menhaden in a surface gill net 25 miles south of Petit Bois Island, Alabama, where the water was slightly over 19.8 fathoms deep. On February 21, 1959, C. E. Dawson, of the Gulf Coast Research Laboratory staff, took one *Brevoortia patronus*, 87 millimeters long, in a trawl at a depth of 20 fathoms, 18 miles south of Grand Isle, Louisiana. The bottom salinity was 36.2 *per mille*. On December 11, 1959, U. S. Fish and Wildlife Service biologists aboard the *M/V Oregon* caught three *B. patronus* at two Gulf stations, 2694 and 2695, in midwater trawls where the total depths ranged from 40 to 55 fathoms. On December 10, at station 2693, where the depth was 35 fathoms, another specimen was taken by dip net at the surface. These fish ranged from 153 to 199 millimeters in fork length. The locations are approximately 25 nautical miles east of the nearest land, the Pass à la Loutre mouth of the Mississippi River.

Biologists have not studied variations in abundance of Gulf menhaden, but there are other avenues of information. The spread of menhaden plants along the Gulf coast is from Port Arthur, Texas, to Pascagoula, Mississippi, with intermediate locations at Cameron and Empire, Louisiana. These locations are all within working distance of the rich, estuarine waters of the Louisiana coast, and the menhaden crews fish these waters most heavily.

The U. S. Fish and Wildlife Service records fluctuations in annual production of fishing areas. Mr. Hermes Hague of the Statistical Section has determined the source of Mississippi menhaden landings by the interview method. His records show that from 1954 to 1958, inclusive, Louisiana waters produced almost 70 percent of the menhaden landed in Mississippi. Interviews[3] with Texas menhaden plant operators indicated that they were of the opinion that over the past 5 years Louisiana waters yielded about 60 percent of the menhaden landed in Texas. Louisiana plants handle the major part of the annual menhaden catch and almost all of it comes from their own waters (Table 1). From 1954 to 1958, inclusive, about 86 percent of the average annual 450-million-pound catch came from Louisiana waters.

Brevoortia gunteri Hildebrand, 1948

Hildebrand (1948) described this small-scaled menhaden from specimens taken in Texas waters and "one half-grown specimen from the vicinity of Grand Isle, La." He gave the range of *B. gunteri* as Grand Isle, Louisiana, to the mouth of the Rio Grande, Texas. The Rio Grande records were based on

[2]Christmas, J. Y., G. Gunter, and E. C. Whatley. Manuscript. A study of fishes caught around the mouth of the Mississippi River and in Mississippi sound in menhaden purse seines.

[3]Conducted by Hermes Hague of the U. S. Fish and Wildlife Service.

TABLE 1.—*Menhaden landings of the Gulf states for the years 1954-1958, and estimated catches from Louisiana waters landed in other states*[1]

[Thousands of pounds]

Area	Total landings	Catch from Louisiana	Percentage from Louisiana
Louisiana	1,293,554	1,293,554	100.0
Mississippi	645,630	451,117	69.9
Texas	297,162[2]	187,297[2]	60.0[2]
Florida	11,084	0	0.0
Gulf	2,247,430	1,931,968	86.0

[1]Compiled from interviews by Hermes Hague; Fishery Statistics of the United States, 1954 to 1957 (U. S. Fish and Wildlife Service Statistical Digests 41-44) and Gulf Fisheries 1958 (U. S. Fish and Wildlife Service C.F.S. No. 2165).
[2]Estimates.

Goode's (1878) paratypes of *B. patronus* which Hildebrand (1948) found. Goode included two species. The fish from the mouth of the Rio Grande were really *B. gunteri.*

Hildebrand (1955) reported *B. gunteri* from the Gulf of Campeche west of Punta Morros, Mexico, thereby extending the range of the species, as well as the genus, far to the southward in the Gulf. Suttkus (1958) suggested that H. Hildebrand's specimens may have been *B. smithi* rather than *B. gunteri.* Hildebrand, however, noted among other things the shape of the ventral fins of the eight specimens reported from Campeche, a reliable distinguishing character, and the report of *B. gunteri* from Campeche is doubtless correct. Hildebrand (p. 200) used the phrase ". . . the discovery of this species off the coast of Tamaulipas and Campeche by the present writer . . .", but made no further mention of *B. gunteri* off Tamaulipas in his 1955 paper nor in a previous one (Hildebrand, 1954) which described trawl catches off Tamaulipas. Later Hildebrand (1958) listed *B. gunteri* as rare in the Laguna Madre de Tamaulipas, and stated the fish was seen in the catch of a commercial fisherman at Boca Ciega, just south of the Rio Grande. In May 1956, H. H. Hildebrand loaned to Edgar Arnold, of the Fish and Wildlife Service, a specimen of *B. gunteri,* 24 centimeters long, from Vera Cruz.

Caldwell's (1954) record of *B. gunteri* from Way Key (Cedar Keys), Florida, actually depended on a specimen of *B. smithi* (Suttkus, 1958), and the known eastern limit of *B. gunteri* remains at Grand Isle, Louisiana, as stated by Hildebrand (1948). Very few specimens of *B. gunteri* have been reported from the eastern part of its range. S. F. Hildebrand listed specimens from Galveston and Grand Isle, the latter being the only record from Louisiana. Suttkus (1958) expressed the opinion that *B. gunteri* did not extend east of Grand Isle.

James Cating and William Haskell, of the Pascagoula Laboratory of the U. S. Fish and Wildlife Service, gave us several fine-scaled menhaden, which were taken by trawlers that brought mixed catches of "industrial" fishes to cat-food plants in Pascagoula (Table 2). Three specimens of *B. gunteri* came from the Grand Isle region and 24 came from off the mouth of Grand Bayou Pass which leads into Bastian Bay. The latter locality is west of the Mississippi River and about 15 miles east of Grand Isle. One specimen, taken near the Chandeleur Islands in Chandeleur Sound

TABLE 2.—*Dates, depths, and fishing areas of trawl caught menhaden landed at Pascagoula, Mississippi*

Date	Location	Depth (fathoms)	Number of specimens
Brevoortia gunteri			
7-21-59	Gulf of Mexico off Grand Isle, Louisiana	6	2
7-30-59	Gulf off Barataria Pass, Louisiana	7	1
9-17-59	Gulf off Grand Bayou Pass into Bastian Bay, Louisiana	5-7	5
9-25-59	Gulf off Grand Bayou Pass into Bastian Bay, Louisiana	7-8	2
9-25-59	Chandeleur Sound NW of North Island, Louisiana (16 *B. patronus* in sample)	2½	1
9-30-59	Gulf off Scofield Bayou, Louisiana (1 *B. patronus* in sample)	4-8	19
Brevoortia smithi			
7-8-59	Gulf of Mexico east of Mobile Ship Channel	8	4
7-29-59	Chandeleur Sound, Louisiana, off Cat Island Channel (9 *B. patronus* in sample	2-3	1
7-30-59	Gulf off Little Lagoon, Alabama (1 *B. patronus* in sample)	4	2
8-4-59	Gulf off Dauphin Island, Alabama	2-3	2
8-19-59	Chandeleur Sound, NW of North Island, Louisiana (2 *B. patronus* in sample)	3-5	2
8-21-59	Gulf between Mobile Ship Channel and Little Lagoon, Alabama	4-7	7
9-10-59	Petit Bois Island, Mississippi	—	2
9-17-59	Gulf off Perdido Bay, Alabama (1 *B. patronus* in sample)	3-5	2
9-24-59	Chandeleur Sound, WNW of North Island, Louisiana	2-3	1
9-25-59	Chandeleur Sound, NW of North Island, Louisiana (16 *B. patronus* in sample)	2½	1
10-2-59	West of Sand Island Light off Dauphin Island, Alabama	3-4	1

on September 25, 1959, was the first record east of the Mississippi River. The Chandeleur locality is about 70 miles northeast of Grand Isle, but about 120 miles from there by the seaward route around the Mississippi delta.

Gunter (1945) found *B. gunteri* in brackish-water bays. Later he recorded it from fresh water in the Mission River of Texas and listed it as euryhaline (Gunter, 1956), in which he was followed by Hubbs (1958). Less is known about the offshore range. Fish were taken in hauls at 8 fathoms, the maximum depth known for the species (Table 2). Simmons (1957) reported *B. gunteri* as common in the Laguna Madre of Texas at salinities from 20 to 60 *per mille*, and uncommon above 60.

Gunter (1945) believed the species was very common in Aransas and Copano bays, but possibly the smaller, more numerous fish were *B. patronus*. Gunter, however, caught considerable numbers of larger fish from which the type and paratypes were selected. The species is not common in the menhaden catches from Louisiana and we know of only one specimen, taken off Isles Dernières, west of Grand Isle. The available information indicates that *B. gunteri* is more common in Texas waters than in Louisiana.

Brevoortia smithi Hildebrand, 1941

B. smithi is a fine-scaled menhaden for which Hildebrand (1948) gave a range from Beaufort, North Carolina, to Indian River, Florida, saying "presumably Indian River City." V. G. Springer told us he had also taken *B. smithi* from the St. Lucie Estuary, which empties into the Indian River (coastal lagoon) about 100 miles south of Indian River City. S. F. Hildebrand learned later that *B. smithi* is also an inhabitant of the Florida west coast (Suttkus, 1958), but the account was not published. Suttkus independently made the same discovery and gave the known range of *B. smithi* in the Gulf of Mexico as Cedar Keys, Florida, to Placida, Florida. Hall and Gunter have taken small specimens from the Caloosahatchee River, thereby extending the range southward about 30 miles. Gunter (1956) and Briggs (1958) listed the species as euryhaline.

Suttkus (1958) was of the opinion that *B. gunteri* and *B. smithi* were widely separated geographically and resided in the western and eastern Gulf, respectively, with both species being overlapped in range by the more abundant *B. patronus*. Actually, the eastern and western Gulf species run together in Chandeleur Sound, Louisiana, the only known locality where three species of menhaden may be taken together.

The localities where *B. smithi* was caught by trawlers for industrial fish landed at Pascagoula, Mississippi, are shown in Table 2. Eighteen specimens were taken in Alabama waters, three in Mississippi waters, and four in Chandeleur Sound, Louisiana. A catch made by the *Deacon's Daughter* on September 25, 1959, should be noted particularly because one *B. smithi*, one *B. gunteri*, and several *B. patronus* were taken from this load, which contained more than 35,000 pounds of fish. The load was not all taken in the same drag or on the same day, but the entire catch was made in the same general area.

COMPARISON OF *Brevoortia gunteri* AND *Brevoortia smithi*

A comparison of the measurements and counts of certain characters for the specimens of *B. gunteri* and *B. smithi* taken during the present study is shown in Table 3. All the specimens fall within the limits given

TABLE 3.—*Summary of some meristic characters and measurements of fine-scaled species of* Brevoortia

[Measurements are expressed as percentage of standard length. The 25 specimens of *B. smithi* range from 191 to 257 millimeters standard length, mean 222.2 millimeters; the 30 specimens of *B. gunteri* range from 214 to 264 millimeters, mean 235.6 millimeters.]

	Number of vertebrae				
	43	44	45	46	Mean
B. smithi	—	1	15	9	45.3
B. gunteri	14	16	—	-	43.6

	Number of ventral scutes						
	28	29	30	31	32	33	Mean
B. smithi	—	—	8	9	5	3	31.1
B. gunteri	6	19	5	—	—	—	29.0

	Number of modified predorsal scales											
	35	36	37	38	39	40	41	42	43	44	45	Mean
B. smithi	1	1	—	—	2	3	1	2	6	4	3	41.9
B. gunteri	—	1	2	3	5	9	4	2	2	2	—	40.0

	Length of head						
	29	30	31	32	33	34	Mean
B. smithi	9	12	4	—	—	—	29.8
B. gunteri	—	—	2	13	12	3	32.4

	Depth of head							
	26	27	28	29	30	31	32	Mean
B. smithi	3	7	12	3	—	—	—	27.4
B. gunteri	—	—	1	4	17	7	1	30.1

	Length of pectoral fin						
	17	18	19	20	21	22	Mean
B. smithi	1	8	6	8	2	—	19.0
B. gunteri	—	—	6	13	6	4	20.3

by Hildebrand (1948) and Suttkus (1958) except that one *B. smithi* from east of the Mobile ship channel had 44 vertebrae, the first overlap in this character with *B. gunteri* that has been found.

Four specimens of *B. smithi*, 182 to 244 millimeters in standard length taken in September 1959 by three boats, have not been examined in detail; three came from off Dauphin Island, Alabama, and one came from off St. Petersburg, Florida. All examples of the fine-scaled menhaden reported here were adults, and were considerably larger than the *B. patronus* generally landed in the menhaden fishery. It seems that *B. smithi* and *B. gunteri* attain a larger size than *B. patronus*.

The places of spawning and the nursery areas of the two fine-scaled menhaden from the central Gulf coast are unknown. Presumably the fish grow up in a bay or estuary. Suttkus, however, found no *B. gunteri* in Lake Pontchartrain. Gunter and Shell (1958) found no young *B. gunteri* in White or Grand Lakes in western Louisiana, and the present authors have found neither immature *B. gunteri* nor *B. smithi* in Mississippi during 2 years of collecting small menhaden. Suttkus (1958, p. 405) said, "Certainly if *B. gunteri* does occur east of Grand Isle it does not frequent the brackish water habitat noted for it in Texas waters by Gunter (1945). The above statement is based upon several years of study of Lake Ponchartrain *(sic)* and adjoining brackish water areas during which time many thousands of specimens were examined and all were referred to the species *B. patronus* (Suttkus, 1956). Furthermore, I have examined many specimens from Mississippi, Alabama and west Florida coasts and all prove to be *B. patronus*." The fact remains that the adults of both species have been found in Louisiana waters east of the Mississippi River, and *B. smithi* has also been taken in the waters of Mississippi and Alabama. It is possible that *B. smithi* has only recently moved into the area, but it is more probable that it has been there for a long time and has only been collected since attention has been focused upon menhaden.

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Use of Branchiostegal Rays to Determine Age of Lake Trout, *Salvelinus namaycush* (Walbaum)[1]

Ross V. Bulkley
U. S. Bureau of Sport Fisheries and Wildlife
Logan, Utah

ABSTRACT

The ages of 342 lake trout from Fish Lake, Utah, and Lake Michigan were determined from branchiostegal rays. Most annuli were located without magnification. For back calculations of growth, rays were projected at a magnification of 3.4X. Evidence presented in support of the method includes agreement in size of ray and body size, agreement between number of annuli and size of fish, increase in new growth on rays as the growing season progressed, similarity of paired bones from the same fish, agreement between calculated and empirical lengths, and agreement in age with scale readings. Assigned age of 37 known-age fish agreed with actual ages. The method is satisfactory for aging lake trout, but less satisfactory than the scale method for back calculations of growth.

INTRODUCTION

Determination of the age of lake trout, *Salvelinus namaycush* (Walbaum), by examination of scales is difficult. Some workers have successfully aged lake trout by this method, but much training and experience are necessary to become proficient. Age of older fish is especially difficult to determine from scales. Because the lack of an easy and dependable method of aging hampers growth studies of lake trout in Utah lakes, a study was initiated at Fish Lake, Utah, in 1956 to determine the value of branchiostegal rays as growth indicators. The branchiostegal rays are small, translucent bones (usually 13 in lake trout) located in the branchiostegal membrane.

Structures other than scales which have been used for determining age composition and growth rates include vertebrae, otoliths, fin rays, and the opercular bone (Menon, 1950). Of the bones considered for use in determining age of lake trout, the branchiostegal rays were considered most promising because the markings seemed to have all of the characteristics of annuli and the bones were easy to obtain. In Utah studies most lake trout samples come from anglers who do not want their fish defaced by the removal of large or deeply-centered bones in the head or body. This feeling is especially true with regard to larger fish which the fisherman wishes to mount or photograph. For this reason neither the opercular bone nor the vertebrae are suitable. The small size and location of the branchiostegal rays eliminate this difficulty in obtaining specimens since one ray on either side of the head can be removed with little damage, or obtained easily if fishermen remove the isthmus and branchiostegal membrane when cleaning their fish. Another advantage in using the rays is that the careful removal of a single ray from living fish produces only a superficial wound, thus making it possible to check the age of a fish without killing it.

Fish of unknown age used in the study were caught by fishermen at Fish Lake, Utah. This lake is the best habitat for lake trout in Utah and is noted for its productivity. It is located in Fish Lake National Forest, Sevier County and lies at an elevation of 8,800 feet. The lake was formed by a graben and is oligotrophic in nature. It is 5¼ miles in length, has an average width of three-fourths of a mile, and a surface area of about 2,500 acres. Water temperatures were measured regularly from June 16 to September 17 in 1956 with a bathythermograph. Surface temperatures varied from 51° to 63° F., and a distinct thermocline was present to a depth of 60 feet. The hypolimnion remained at a fairly constant temperature of 43° to 44° F. Lake trout were introduced into Fish Lake in 1906.

COLLECTION AND PREPARATION OF RAYS

Samples of scales were secured from 305 lake trout captured in 1956 at Fish Lake. Total lengths were measured to the nearest

[1]The study was Federal Aid Project F.M.-27, financed with Dingell-Johnson funds under the supervision of the Utah Department of Fish and Game.

one-eighth of an inch with a steel tape, and weights were determined to the nearest ounce. Scales from each fish were taken from a location between the anterior end of the dorsal fin and the lateral line. The outer branchiostegal rays adjacent to the left and right opercular bones were also taken from each fish. These rays were selected because they are the largest and most ossified in the branchiostegal membrane. Both rays were taken since occasionally one was deformed or broken. They were removed by inserting a sharp knife along each side of the ray to sever the connecting tissue, using care to avoid cutting off the base of the ray containing the focus. Rays were prepared for reading by placing them in boiling water for 30 to 60 seconds before the skin had dried and then removing the flesh.

DEFINITION OF ANNULI

The structure of branchiostegal rays of lake trout suggests that they grow larger by the deposition of cells on the posterior edge. As this edge grows outward, history of growth is recorded in a manner similar to that noted on scales. The rays of fish from Fish Lake were marked by a series of white opaque bands separated by transparent lines that ran parallel to the outer edge of the ray (Figure 1). These lines gave the appearance of being the outer edge of the ray at one time.

It was postulated that the narrow, transparent lines extending from the posterior end of the ray along the full length of the lateral field were annuli. These narrow lines were assumed to be winter growth and the broad, white bands to be summer growth. The exact division point was often difficult to locate because on older fish the white area occasionally blended into these transparent lines and obscured them. A slight ripple of varying distinctness in the structure of the ray was also present at each of the areas defined as annuli. The direction of growth on the ray appeared to change immediately after the annulus was laid down. These ripples stood out distinctly enough to mark the annuli on most rays if the ray was held so that light reflected from it to the eye. False annuli were often present and were occasionally difficult to separate from true annuli. Most false annuli were indistinct, did not extend far into the lateral field of the ray, and lacked the characteristic ripple in the ray structure. The annuli of fish aged as 3 years or younger were not as distinct as the annuli on the rays

FIGURE 1.—Branchiostegal rays and scale from a Fish Lake lake trout assigned to age-group VII.

of fish older than 3 years, partly because there was incomplete ossification. Markings on the rays of fish older than age-group V were especially distinct.

McConnell (1952), working with the opercular bone of carp, had some difficulty in locating the first annulus because there was a thickening of the bone around the fulcrum. The branchiostegal ray of lake trout is much thinner than the opercular bone, however, and the presence of the first annulus did not appear to be a problem until comparison with the scales revealed that the first annulus was often overlooked in reading the rays. The annuli were seen most easily against a dark background in highly diffused sunlight or fluorescent light. Various stains were tested on the rays, but none were of value in making the annuli more distinct.

Each ray was read independently three times to determine the age of the fish. The annuli on most rays were discernible without optical equipment, but doubtful rays were examined with a large reading glass or a hand lens. After all annuli on a ray had been located, they were marked with a dot of India ink to aid in measurement for back calculations of growth.

Annuli near the edge of the ray on older fish were bunched closely together so that direct measurement from the ray focus to the outer annuli was difficult. The rays were placed in a transparent plastic envelope and inserted in a lantern slide projector. An enlargement of 3.4 diameters was sufficient for accurate measurement with a minimum loss of definition. Tag-board strips were used for recording the projected ray length and distance from the focus to each annulus. The strip was bent for measurement so that it lay parallel to the curved inner edge of the enlarged image (Figure 2), because the curved measurement was assumed to be closer to the true pattern of growth. Allowance for curvature in the other plane was unnecessary since the rays were almost flat. The measurements for growth determinations were made from the focus to the posterior-most part of each annulus so that all measurements would be uniform.

EVALUATION OF THE METHOD

Accuracy of the aging technique was checked by making a number of comparisons and by the use of known-age fish. A reliable

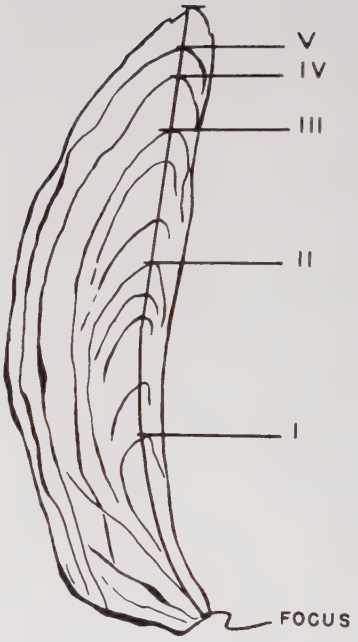

FIGURE 2.—Method used to measure distance from focus of ray to each annulus (figure slightly diagrammatic).

method of aging fish by examination of a body structure should satisfy the following requirements: 1) there must be good correlation between the size of the structure used for age determination and size of the fish; 2) the number of annuli on the structure must increase with increase in size of the fish; 3) the outer margin of the structure should grow outward from the last annulus as the growing season progresses; 4) paired or similar structures from the same fish must have the same number of annuli present; 5) calculated lengths by the method should agree with empirical length of younger fish; and 6) age determined by the method should agree with age determined by other methods.

Ray and body length

In order for the branchiostegal rays to be accurate indicators of age, they must be closely correlated with body size. There was high correlation ($r = 0.961$) between the length of branchiostegal rays and body length, and the body and the rays grew longer at a constant ratio. The average ray length (x 3.4) for fish in the 9.0-9.9-inch length group was 1.93 inches. Ray length increased for each length group up to the 38.0-38.9-inch group which had a ray length (x 3.4) of 6.89

inches. The relationship between body length and branchiostegal ray length was determined from 305 specimens and was expressed adequately by the linear formula:

$$L = 0.605 + 5.486R$$

where L is the total length in inches and R is the total length (x 3.4) of the ray in inches (Figure 3).

Annuli number and body size

The number of annuli present on the branchiostegal rays increased directly with the size of the fish. A comparison was made between the number of annuli counted on the ray and the length and weight of the fish. Both the length and weight increased in gradual steps with increases in assigned age up to age-group X (Table 1). The relationship was not as distinct in the older groups where the number of fish in an age group was very small.

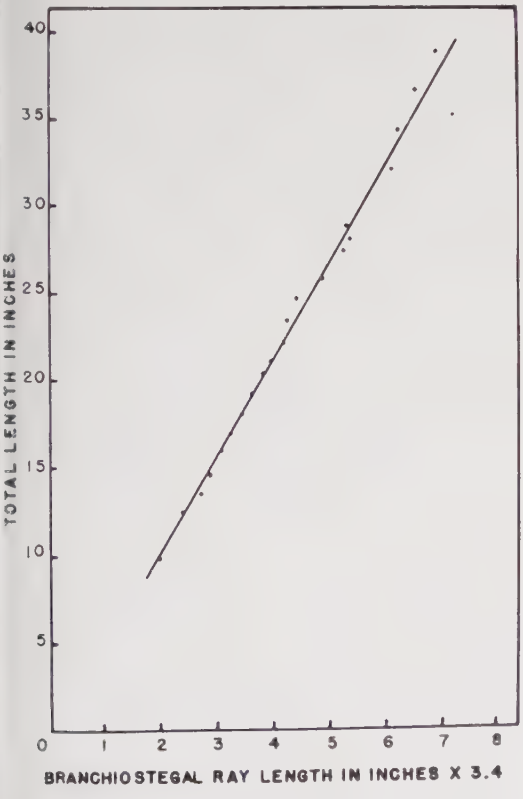

FIGURE 3.—Body-branchiostegal ray relationship of Fish Lake lake trout as determined from 305 fish collected in 1956.

TABLE 1.—*Mean total length (inches) and weight (pounds) for each age group of 294 Fish Lake lake trout*

[Age determined from branchiostegal rays]

Age group	Number of fish	Mean length	Standard deviation	Mean weight	Standard deviation
I	1	10.5	—	—	—
II	9	13.1	0.56	0.64	0.08
III	10	14.8	1.10	0.92	0.63
IV	44	16.8	0.82	1.44	0.76
V	66	18.3	1.04	1.87	0.41
VI	99	20.3	1.18	2.66	0.50
VII	33	22.5	1.28	3.75	0.68
VIII	11	26.6	1.49	6.20	1.45
IX	5	27.6	2.26	8.67	1.75
X	4	31.6	3.13	12.29	4.04
XI	1	29.1	—	7.75	—
XII	2	35.9	4.66	16.25	3.35
XIII	2	32.6	2.64	14.32	4.52
XIV	1	30.0	—	—	—
XV	2	35.0	1.95	14.19	2.04
XVI	3	36.5	1.25	15.88	0.71
XVII	1	34.5	—	15.50	—

New growth on rays

Another verification of the method is a consistent increase in marginal growth on the ray throughout the growing season. New growth was visible on many of the branchiostegal rays of Fish Lake lake trout caught during June. The rays of fish assigned to age-groups IV, V, and VI were examined to see if the amount of new growth increased as the summer progressed. Only these age groups were used because there is wide variation in rate of growth in very young and very old fish. Trout were separated according to month of capture, and the average width of the branchiostegal rays from the outer annulus to the ray edge for all fish captured in each month was determined (Table 2). Progressively increased growth from June to September was noted, except that the average new growths for July and August were found to be the same. It is assumed that variations in sampling and use of different individuals with varying growth rates accounted for the apparent failure to grow in August.

Similarity of rays on same fish

Two branchiostegal rays from opposite sides of the head of each fish were compared to determine whether the number of annuli were the same on each. The rays were very similar (Figure 1) and the number of annuli was always the same on each pair examined. Occasionally an annulus on one ray would be more distinct than that on its mate, particularly near the base of the ray; but after comparison, both annuli could be located.

TABLE 2.—*Amount of new growth on branchiostegal rays of age-group IV, V, and VI lake trout from Fish Lake captured June to September 1956.*

Item	June	July	August	September
Mean distance from annulus to ray edge (millimeters)	0.101	0.116	0.116	0.126
Number of fish	84	59	55	18

Calculated vs. empirical lengths

Calculations of past growth (Table 3) were made with the aid of a nomograph, as described by Hile (1950). Comparison was then made between back calculations of length determined from branchiostegal rays and measured lengths of younger fish. Calculated lengths from combined age groups were reasonably consistent with mean lengths at capture up to age-group V. The calculated lengths of fish in age-group VI and above were generally larger than lengths at capture. Some of the difference may have been due to individual variations as the result of small sample size. Calculated lengths derived from increment summation appeared less accurate than mean lengths from combined age groups, except that the apparent decrease in length between age-groups XVI and XVII was eliminated.

Branchiostegal rays vs. scales

Age determined by the branchiostegal rays should agree with the age read from scales of the same fish. Scales taken from lake trout o which age had been determined from th branchiostegal rays were mounted and ag assigned by scale reading. On some of th scales a growth check was located near th focus. As a number of lake trout fingerling are planted annually in Fish Lake, it was as sumed that this check was a planting check Cable (1956) found a similar check on scale of Lake Michigan fish and called it the C mark. Scales of fish older than age-grou VIII were difficult to read, and the accurac of the age assigned to these fish is doubtfu Comparison was then made between age de termined by reading branchiostegal rays an age assigned by reading scales (Figure 1) Both the rays and scales were again studie independently if the age assigned by the tw methods disagreed. Any errors found in pre vious readings were corrected. If no definit errors were located, the assigned ages wer not changed. Most of the disagreement in ag was caused by overlooking a partially ol scured first annulus on the rays.

In the first comparison, 71 percent of th scales agreed in age with the branchiostega rays. After an independent rereading o scales and rays, agreement in age was reache on 94 percent of the fish. The two method agreed on the age of all fish up to age-grou V. Differences in age-groups VI and VII di not show any particular trend. Most of th disagreement was in fish older than 7 years Where the two methods disagreed in the olde fish, a younger age was assigned by the scal

TABLE 3.—*Mean calculated total lengths and growth increments, determined from branchiostegal rays, fo 295 Fish Lake lake trout collected during summer of 1956*

[All lengths in inches]

Age group	Number of fish	Mean length at capture	Year of life																
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
I	1	10.5	8.5																
II	9	13.7	8.8	12.2															
III	10	15.9	8.4	12.3	14.8														
IV	44	17.5	8.1	12.0	14.7	16.5													
V	66	19.1	7.1	10.7	13.8	16.4	18.2												
VI	99	21.0	6.9	10.6	13.8	16.4	18.5	20.2											
VII	33	23.4	7.6	12.0	15.3	17.7	19.7	21.4	22.8										
VIII	11	27.7	7.4	12.2	15.5	18.3	20.3	22.5	24.5	26.2									
IX	5	28.5	10.0	13.6	16.8	19.4	21.3	23.2	25.2	26.6	27.7								
X	4	31.1	8.0	12.9	17.2	20.7	23.3	25.3	27.1	28.3	29.5	30.4							
XI	1	30.2	9.5	15.5	18.6	21.3	22.9	24.3	25.8	26.7	27.9	29.0	29.7						
XII	2	36.6	8.4	13.2	17.6	19.8	22.9	26.7	28.8	30.6	32.2	33.6	34.6	35.6					
XIII	2	34.6	8.9	12.9	16.8	19.7	21.8	23.5	25.8	27.7	29.4	30.8	32.1	33.1	34.1				
XIV	2	34.6	10.8	15.9	18.5	21.5	24.0	25.4	27.4	28.8	30.0	31.1	31.9	32.3	32.9	33.2			
XV	2	35.6	8.7	13.3	16.6	20.9	23.2	25.2	26.8	28.9	30.0	31.2	32.2	32.8	33.5	34.4	34.9		
XVI	3	38.3	7.5	12.1	16.2	19.6	23.2	26.1	29.5	31.5	32.8	33.8	34.7	35.4	36.3	36.8	37.4	37.9	
XVII	1	36.4	9.4	13.8	16.7	19.7	21.7	23.2	25.0	26.0	27.4	28.5	29.6	30.8	31.6	33.5	34.5	35.3	36.0
Weighted mean length			7.5	11.4	14.5	16.9	19.1	21.2	24.4	27.7	29.7	31.4	32.7	33.7	34.6	34.9	36.1	37.2	36.0
Increments of growth			7.5	4.0	3.1	2.5	2.0	1.8	1.8	1.6	1.3	1.1	1.0	0.8	0.8	0.7	0.7	0.6	0.7
Mean length by increment summation			7.5	11.5	14.6	17.1	19.1	20.9	22.7	24.3	25.6	26.7	27.7	28.5	29.3	30.0	30.7	31.3	32.0

eadings than by the ray readings. The reason for a larger number of growth checks on he rays is unknown. Either the outer annuli were not readily discernible on the scales of he older fish, or interruptions in growth had nore effect on the rays than on the scales. Examination of rays and scales of known-age ish over 7 years of age will be necessary to letermine which of the two structures records he more correct pattern of annuli.

Calculated lengths obtained by the two nethods were also compared. An assumed *Y* ntercept of 1.77 inches (45 millimeters) was ised in computing growth increments by the cale method. There was considerable difference in lengths of younger age groups alculated by the two methods (Table 4). Calculated lengths from the scales averaged 2.2 inches smaller than those calculated from ays for age-groups I to VI. Lengths for age-groups VII to XIII were more similar. A *t* est of differences between the length estimates up to age-group XIII showed a value of 1.498, which was nonsignificant at the 0.05-percent evel. Differences in calculated lengths, therefore, were not believed to be excessive where ll age groups were involved.

Calculated lengths for young fish by the ray method were still higher than expected for the relatively slow-growing lake trout. In comparing lengths calculated by the two methods with growth studies from other areas, the scale method agreed more closely than the ray method (Table 5). Lengths of young fish determined by the ray method were high in comparison to all other studies examined. Direct comparison was complicated by two factors. Fish Lake is especially productive and growth of other trout species is rapid (Sigler, 1953). In addition, the number of hatchery fish in the sample was unknown. Many of the fish could have been planted as fingerlings and would have been larger than expected for their age.

Failure to observe the first annulus on the rays was not the cause of the difference, as this was corrected prior to calculating growth rates. Age agreement between the scales and rays in young fish was very close. Agreement in calculated lengths of older age groups by the two methods supported the conclusion that some error other than in aging was the source of the differences. The use of an improper *Y* intercept could have caused the high calculated lengths obtained for the younger age groups.

Known-age fish

Branchiostegal rays from 37 Lake Michigan fish of known age (Cable, 1956) ranging from 3 to 5 years old were examined without a knowledge of the age of any particular fish. These lake trout were originally preserved in formalin and then transferred to alcohol. Since the markings on the rays were not as clear as those found on branchiostegal rays of fish from Fish Lake, it was assumed that some deterioration of the rays had occurred while the fish were in the preservatives. The characteristic ripples on the rays defining the annuli were visible so these were used for assigning the age of the fish.

An unbiased reading of the rays revealed that the number of annuli on 30 of the 37 rays agreed with the known age of the fish. Seven fish were assigned an age one year younger than their actual age. The probable reason for this disagreement was the date of capture of these seven fish which were taken between February 4 and May 7, prior to the principal growing season. Since Cable (1956) indicated that only 50 percent of Lake Michigan lake trout show new growth on the scales by June, it would not be unusual to find that fish captured before May were without new growth on the rays. The final annulus of the seven fish was assumed to be on the edge of

TABLE 4.—*Calculated total lengths and growth increments of Fish Lake lake trout by the scale and branchiostegal ray methods — expressed in inches*

Method	Age groups															
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
Scales																	
Calculated lengths	5.4	8.4	11.6	14.8	17.5	20.0	23.1	27.2	30.3	32.4	32.0	33.0	34.3	—	—	—	—
Growth increments	5.4	3.0	3.3	3.2	2.9	2.4	2.6	2.6	2.2	2.1	1.3	1.8	1.3	—	-	—	-
Rays																	
Calculated lengths	7.5	11.4	14.5	16.9	19.1	21.2	24.4	27.7	29.7	31.4	32.7	33.7	34.6	34.9	36.1	37.2	36.0
Growth increments	7.5	4.0	3.1	2.5	2.0	1.8	1.8	1.6	1.3	1.1	1.0	0.8	0.8	0.7	0.7	0.6	0.7

TABLE 5.—*Growth rates of Fish Lake lake trout and lake trout from other waters—expressed in inches*

Water	Year of life completed												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Fish Lake (rays)[1]	7.5	11.4	14.5	16.9	19.1	21.2	24.4	27.7	29.7	31.4	32.7	33.7	34.6
Fish Lake (scales)[2]	5.4	8.4	11.6	14.8	17.5	20.0	23.1	27.2	30.3	32.4	32.0	33.0	34.3
Lake Michigan[1] (Cable, 1956)	5.9	8.7	11.2	13.6	15.5	15.2	—			—	—	—	—
Lake Michigan[1] (Van Oosten, 1950)	4.9	8.5	11.9	15.4	18.4	21.1	23.1	24.5	28.0	—	—	—	—
Lake Superior[3] (Eschmeyer, 1956)	3.9	6.7	8.6	—	—	—		—	—	—	—	—	—

[1]Calculated total length.
[2]Calculated total length with *Y* intercept of 1.77 inches.
[3]Total length at capture.

the ray, but without sufficient new growth to mark its location. Under this assumption, all assigned ages agreed with the known age of the 37 fish.

CONCLUSIONS

From the data presented it was concluded that the determination of age of lake trout from Fish Lake, Utah, by branchiostegal rays is possible, but that further examination of fish from other waters is necessary to determine the general applicability of the method. Branchiostegal rays were easier to read than scales, especially on older fish. The annuli were located with minimum difficulty on most of the rays examined, except for the initial annulus. Indirect evidence agreed with the ages assigned by the method, and readings of rays from known-age Lake Michigan trout appeared correct. Difficulty in determining the exact location of the annuli on the rays decreased the accuracy of calculated lengths. High calculated lengths for young fish were assumed to be due to the use of an incorrect *Y* intercept. Hence, the body-branchiostegal ray relationship needs to be re-examined. The method is probably most valuable to substantiate scale readings or to use in cases where only age frequencies of a sample are desired.

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Use of Rotenone in Restoring Balance to Overcrowded Fish Populations in Alabama Lakes

ARCHIE D. HOOPER AND JOHNIE H. CRANCE
Alabama Department of Conservation
Montgomery, Alabama

ABSTRACT

Overcrowded sunfish populations have occurred in 5 of Alabama's 18 State-owned public fishing lakes. They have resulted from a combination of factors, including presence of undesirable fish species, infestation with a branched alga, fish kills, loss of fish over the spillway, and heavy fishing. These overcrowded populations were usually balanced by three to seven marginal, or a combination of marginal and sectional, treatments with rotenone applied usually during September and October. The annual average catch by anglers was 193.4 pounds per acre during the years that the five lakes contained balanced fish populations, and 132.7 pounds per acre during the years that the lakes contained overcrowded forage fish populations. Although these lakes contained overcrowded forage fish populations for varying periods of time, an annual average of 156 fishermen per acre caught 174.5 pounds of fish during the 5 to 8 years that the lakes were open to continuous public fishing. This high sustained harvest was attributed to prompt correction of unbalanced fish populations by partial poisoning with rotenone.

INTRODUCTION

Alabama's State-owned and managed public-fishing-lake program was initiated in 1948. At the present time the Alabama Department of Conservation owns and manages 18 lakes ranging in size from 32 to 250 acres and comprising a total of 1,444 acres. Construction of the lakes was limited to sites having suitable topography, subsoil, and water supply as suggested by Lawrence (1949), and was confined to areas of the State found to have inadequate fishing waters (Byrd and Moss, 1952). The present study reports on Coffee Lake (80 acres), Barbour Lake (75 acres), Crenshaw Lake (53 acres), Pike Lake (45 acres), and Cullman Lake (32 acres), which were open to continuous fishing for 5 to 8 years.

Lake construction was usually completed in late summer. Immediately prior to impoundment in the fall, all waters in the lake and watershed were treated two or three times with 5 to 10 p.p.m. of 5 percent rotenone to eliminate native fish. The lakes were usually stocked during October or November about 4 weeks after final treatment of the lake areas with rotenone. From 1,000 to 1,500 hatchery-reared sunfish (2 to 3 inches long) per acre were planted. Approximately 85 percent were bluegills *(Lepomis macrochirus)* and 15 percent were redear sunfish *(Lepomis microlophus)*. No distinction is made between these species in the following discussion. One- to two-inch, hatchery-reared largemouth bass *(Micropterus salmoides)* were stocked at rates of 100 to 150 per acre during the following April or May. These stocking rates were within the range recommended by Swingle (1949, 1951, 1952). Fertilization was begun in February following impoundment and was continued at rates recommended by Swingle and Smith (1947). An average of 12 applications of 100 pounds of 8-8-2 (N-P_2O_5-K_2O) per acre or its equivalent was applied annually. The lakes were first opened to fishing about 13 to 14 months after the initial stocking of largemouth bass and remained open from daylight to dark each day thereafter. No size limits were imposed but the creel limit was 20 sunfish and 6 largemouth bass per day. The number of fishermen and the number, weight, and species of their catch were recorded daily by resident lake managers.

Creel data from the lakes were analyzed continuously, and the population balance was estimated by seining during bass and sunfish spawning seasons. Balanced fish populations were considered to be those that yielded satisfactory annual catches of fish and in which there was adequate annual reproduction of bass and sunfish (Swingle, 1945, 1950, 1956). Sunfish populations were considered overcrowded when seining with a ½-inch-mesh seine 50 feet long and 6 feet deep yielded an average of more than 35 intermediate-sized sunfish (3-, 4-, and 5-inch groups) per seine haul and/or when adequate numbers of sunfish fry could not be

found by seining with a 1/6-inch-mesh seine.

Unbalanced fish populations that occurred in the five lakes resulted from overcrowding by sunfish and/or undesirable species of fish, including bullheads *(Ictalurus natalis* and *I. nebulosus)*, crappies *(Pomoxis annularis* and *P. nigromaculatus)*, green sunfish *(Lepomis cyanellus)*, and golden shiners *(Notemigonus crysoleucas)*. These competitive species either survived rotenone poisoning prior to stocking with hatchery fish, migrated over the spillway into the lake during high water, or were introduced by sportsmen.

One of the principal causes of stunted forage fish populations in impounded waters in the Southeast is heavy weed growths which increase cover and thereby reduce predation by carnivorous fish (Swingle and Smith, 1942). Byrd and Moss (1957) reported that regular fertilization prevented serious weed problems in most of Alabama's State-owned lakes, but *Pithophora*, a branched green alga, contributed to unbalance in Barbour Lake. They also reported that fish kills due to dissolved-oxygen deficiency or unknown fish diseases, loss of fish over the spillway, and heavy fishing pressure or a combination of these factors contributed to the development of overcrowded fish populations. Byrd (1959) reported that an annual average of 162.2 fishermen per acre harvested an average of 174.2 pounds of fish per acre from 12 of Alabama's State-owned lakes which comprised a total of 841 acres and were open to fishing for 2 to 8 years. These 12 lakes include five which were partially poisoned with rotenone to thin crowded forage fish populations.

There is unusually heavy fishing pressure in the State-owned lakes. For example, during an 8-year period the annual average number of fisherman-trips and pounds of fish harvested per acre from one lake (Crenshaw) was 212 and 249, respectively. Swingle (1950) reported that during the process of harvesting large fish from a population, the A_t value (percentage of the total weight of the fish population composed of fish of harvestable size) must necessarily decrease and in a balanced population it must subsequently increase in order to provide a harvestable crop for the following year. While the A_t values are expected to fluctuate, they must fluctuate within the limits of 33 to 90 if balance is to be maintained (Swingle, 1950, 1956). The A_t value would be expected to remain relatively constant with a slow rat of harvest since a simultaneous replacemer would occur as a result of normal growt and reproduction; but a rapid withdrawal c harvestable-sized fish (whether the remova resulted from fishing pressure, fish-kills, c loss of fish over the spillway) could reduc the A_t value below the requirements for ba ance. Any body of water has a maximu carrying capacity for fish that is determine by the species of fish present and the abu dance of available fish foods. A fish popul tion therefore can be composed of a larg number of small fish or a lesser number c larger fish. When the number of harvestabl sized fish within a fish population is drast cally reduced in a short period of time, large quantity of fish foods becomes avai able for the intermediate-sized fish and th few remaining harvestable-sized fish. The in creased quantity of food would result in greatly accelerated rate of growth and/or r production. Under these conditions the and 4-inch intermediate-sized fish and/or th young fish spawned as a result of the in creased food supply could utilize most of th available food before reaching a harvestab size.

Eschmeyer (1937) and Thompson an Bennett (1939) suggested that overcrowde fish populations could be corrected by r stocking after poisoning the entire popul tion, or by draining and restocking. Bec man (1941) reported that an increase growth rate of fish occurred in Standar Lake, Michigan, following the reduction c a stunted fish population by the use of rot none in a section of the lake. Swingl Prather, and Lawrence (1953) reported su cessful use of marginal and/or sectional po soning for correction of overcrowding; hov ever, seining was too time-consuming fc general use.

METHOD OF POISONING

Partial poisoning to correct overcrowdin usually was done in September and October however, two of the lakes were poisoned i June and one in November. Rotenone wa applied between 8:00 a.m. and noon when minimum number of large fish would be ex pected in the shallow water. Applications c rotenone were made only on clear, calm day to reduce the chance that the poison woul move into deep water.

Cubé powder containing approximately 5 ercent rotenone was used most often for par- ial poisoning. Liquid emulsifiable formula- ons containing approximately 5 percent otenone were used occasionally. Cubé powder as mixed with water to form a thick paste hich was applied from a boat by placing it the hand or a ¼-inch-mesh dip net and ragging it under the surface of the water s the boat was propelled by an outboard otor. Emulsifiable rotenone was diluted with to 4 parts of water and applied from the de of a moving boat or by pouring it in e wake of the outboard motor.

Marginal poisoning was done by applying tenone parallel to the shoreline at a dis- nce of 20 to 30 feet from the shore and water less than 3 to 4 feet deep. The rmulations were applied at a rate of 2 unds of 5 percent rotenone per 100 yards shoreline. Three to seven applications were quired to complete marginal poisoning in a ke. The number depended on the degree to hich the fish population was overcrowded d upon the number and size of fish killed uring each application. The time interval etween applications ranged from 3 to 5 days d was determined by the weather condi- ons and the length of time required for in- rmediate-sized sunfish to move into the reviously treated areas.

In sectional poisoning a considerable por- on of the lake, without particular reference the shoreline, was treated. Approximately p.p.m. emulsifiable formulation was used areas of 2.5, 3.0, and 8.0 acres in Bar- our Lake (75 acres) and in areas of 3.0 and .0 acres in Pike Lake (45 acres). The liquid as applied from a boat with a power riven pump and a perforated hose weighted one end. Rotenone was first pumped from e surface to the bottom around the bound- ries of the area that were not adjacent the shoreline and was then distributed over e remainder of the area. Potassium per- anganate ($KMn0_4$) was applied, approxi- ately 1 hour after the poisoning in the 45- re lake, at a rate of approximately 2 p.p.m. dragging a burlap bag containing the mpound over the surface of the area. This as done to detoxify the rotenone and re- ce the kill of adult fish which might have oved into the area (Lawrence, 1956).

An estimate of the weight of fish killed was ade following each treatment. Fish of arvestable size were counted and weighed. An estimate of unharvestable-sized fish was made by counting and weighing fish in measured, representative portions of the shoreline. The minimum weights of individual sunfish, largemouth bass, crappie, and bullheads that were considered to be of harvestable size were 0.1, 0.4, 0.26 and 0.3 pound, respectively.

Fingerling bass were usually restocked at a rate of 100 per acre if spring seining revealed that bluegills were spawning adequately and that bass had failed to spawn successfully. The restocking rate, however, ranged from 25 to 200 per acre, depending upon the amount of sunfish reproduction.

RESULTS OF THE PROGRAM

The results of rotenone treatment and the subsequent history of angling were used to judge the success of the program (Tables 1 and 2). Creel data for each lake are summarized by calendar years; the data obtained from the day the lake was opened to fishing to the end of the first year were excluded.

During the years when the five lakes contained balanced fish populations, an annual average of 161 fishermen per acre harvested an average of 193.4 pounds of fish per acre. These figures can be compared with an average of 146 fishermen per acre who harvested 132.7 pounds annually during the years that the lakes contained overcrowded forage fish populations. During the 5 to 8 years that the lakes were open, the annual average fishing load was 156 fisherman-trips per acre and the average catch was 174.5 pounds per acre. Prompt corrective measures undoubtedly prevented greater reduction in the annual harvest from the lakes and prevented loss of at least 18 months of fishing that would have occurred had it been necessary to drain and restock the lakes. Bullheads and crappie contributed to overcrowded fish populations in Pike, Crenshaw, and Cullman Lakes and were not thinned adequately by either marginal or sectional poisoning.

Success was greatest when partial poisoning was carried on between September and November, a period when sunfish do not spawn in Alabama. It was necessary to kill from 80 to 150 pounds per acre of intermediate-sized sunfish to restore balance to overcrowded sunfish populations in lakes which did not contain crappie.

TABLE 1.—*Results of partial poisoning treatments in five Alabama State-owned lakes*

Lake	Area (acres)	Years open to fishing	Treatments			Estimated pounds of fish killed per acre		
						Bluegills and redear sunfish		Largemouth bass
			Time	Number	Type	Unharvestable[1]	Harvestable	Harvestable
Coffee	80	7	June, 1954	6	Marginal	34	—	—[3]
			Sept.-Oct., 1954	6	Marginal	93	—	—[3]
Barbour	75	5	Sept., 1954	2	Marginal	—[3]	—	—
			Oct., 1954	3	Sectional	231	17	9
			Sept.-Oct., 1957	4	Marginal	108	—	10
Crenshaw	53	8	Sept.-Oct., 1954	6	Marginal	83	—	—
			Sept.-Oct., 1955	5	Marginal	143	2	1
			Sept.-Oct., 1956	7	Marginal	5	—	—
Pike	45	5	Sept., 1955	4	Marginal	115	1	22
			Oct., 1955	2	Sectional	19	—	3
Cullman	32	7	June, 1952	3	Marginal	55	—[3]	—[3]
			Nov., 1953	3	Marginal	100	2	2
			Sept.-Oct., 1957	4	Marginal	10	—	—[3]
			Sept., 1958	7	Marginal	97[4]	—	—[3]

[1]Weighing less than 0.1 pound.
[2]Harvestable size bass were those weighing 0.4 pound or more. In each case less than 0.5 pound of unharvestable size ba per acre was killed.
[3]Less than 0.5 pound per acre.
[4]Includes 8 pounds per acre of crappie weighing less than 0.25 pound each.

Coffee Lake

An attempt was made to restore a balanced population to Coffee Lake (80 acres) by completing a series of six marginal poisonings in the lake during June 1954. Only 34 pounds of intermediate-sized sunfish per acre were killed during the June treatments, but bluegills did not spawn sufficiently during the summer to provide adequate food for young bass. Another series of marginal poisoning treatments was made during September and October of the same year, and 93 pounds of intermediate-sized sunfish per acre were killed. As a result, the population in Coffee Lake was in balance during 1955 and the average harvest by fishermen increased from 64.4 pounds per acre during 1954 to 174.1 pounds in 1955 and 203.4 pounds in 1956 (Table 2). The catch per fisherman-trip was 1.3 pounds in 1955 and 1.8 pounds in 1956 as compared to 0.9 pound in 1954. The annual harvest of fish has remained relatively high and the fish population has remained balanced for 4 years following treatment.

Barbour Lake

Marginal and sectional poisonings were necessary to restore balance to the fish population in Barbour Lake (75 acres) during 1954. Marginal poisonings to reduce the sunfish population were unsuccessful during September 1954 because few sunfish were in the shallow water. Since the creel census an seining records indicated that only a fe bass were present in the lake, sectional po soning was attempted. Three areas of 2.5, 3.0 and 8.0 acres were poisoned during Octobe The sectional poisoning killed an estimate average of 231 pounds per acre of inte mediate-sized sunfish and 9 and 17 pounc per acre of harvestable largemouth bass an sunfish (Table 1). The fish population was i balance the following year and the annu harvest of fish by anglers increased from 71. pounds per acre during 1954 to 130.7 pounc per acre during 1955 (Table 2).

The lake contained an overcrowded popul tion of bluegills again in 1957. It was po soned marginally four times during Septen ber and October, and an estimated average 108 pounds per acre of intermediate-sized su fish and 10 pounds of harvestable bass we killed. This lake contained a balanced fis population the following year and the annu harvest by anglers increased from 109 pounds per acre to 157.1 pounds. The averag catch per fisherman-trip increased approx mately 33 percent (Table 2).

Crenshaw Lake

There was an increase in anglers' annu harvest of fish from Crenshaw Lake (5 acres) during each of the 3 years that th lake was marginally poisoned (Table 2). Th

ake was first treated with a series of six narginal poisonings during September and October 1954 to thin an overcrowded sunfish population. These treatments killed an estimated average of 83 pounds of intermediate-sized sunfish per acre. The following year the annual harvest of fish increased to 268.9 pounds per acre as compared to 164.5 the previous year. Removal of such a high proportion of fish by angling apparently resulted in another overcrowded sunfish population during late summer of 1955 and a second series of five marginal poisonings was used during September and October. These treatments killed an average per acre of 143 pounds of intermediate-sized and 2 pounds of harvestable sunfish.

The following spring (1956) the fish population was in balance. Unfortunately, fishermen had introduced black crappie and reproduction of this species was found in the lake for the first time during June. Seining during late summer of 1956 indicated that sunfish reproduction had ceased and consequently there was insufficient food for the young-of-the-year bass. The overcrowded population probably resulted primarily from the presence of crappie and the high catch of fish (289 pounds per acre) during 1956.

An attempt was made to reduce the overcrowded fish population during September and October 1956. Seven marginal poisonings killed only 5 pounds per acre of intermediate-sized sunfish and none of the 4- and 5-inch crappie which were in deep water at the time the lake was treated. Seining during June 1957 indicated that the fish population had returned to balance. This result may have been brought about by predation on intermediate-sized sunfish and crappie by bass. The catch from the lake remained relatively high and the population remained balanced throughout 1957 and 1958, but seining during the spring of 1959 indicated that the lake was again overpopulated with crappie and harvest by anglers decreased abruptly.

TABLE 2.—*Average harvest by anglers and fisherman-trips in five of Alabama's State-owned lakes open to continuous fishing for 5 to 8 years*

[Harvest expressed in pounds per acre]

Lake	Year	Sunfish[1]	Bass	Bullheads	Crappie	Total	Trips per acre
offee	1952	234.1	31.5	4.8	—	270.4	238
	1953	207.6	28.2	4.5	—	240.3	240
	1954[2]	45.3	14.8	4.3	—	64.4	68
	1955	150.2	15.4	8.5	—	174.1	133
	1956	163.2	33.0	7.2	—	203.4	116
	1957	132.2	37.6	5.4	—	175.2	114
	1958	185.5	17.5	4.3	—	207.3	136
arbour	1954[2]	68.2	3.1	—	—	71.3	67
	1955	120.1	10.1	0.5	—	130.7	112
	1956	97.8	9.5	0.6	—	107.9	125
	1957[2]	102.4	7.1	0.2	—	109.7	111
	1958	150.4	6.6	0.1	—	157.1	118
renshaw	1951	118.6	0.7	2.3	—	121.6	121
	1952	284.6	8.0	7.1	—	299.7	255
	1953	219.3	14.4	3.5	—	237.2	203
	1954[2]	129.7	34.7	0.1	—	164.5	169
	1955[2]	242.2	26.5	0.2	—	268.9	223
	1956[2]	248.6	30.4	10.1	—	289.1	226
	1957	282.3	21.2	0.4	28.2	332.1	261
	1958	233.4	19.4	3.5	23.9	280.2	239
ake	1954	64.4	28.4	72.0	—	164.8	135
	1955[2]	59.0	20.4	44.9	—	124.3	135
	1956	63.1	5.2	29.8	—	98.1	83
	1957	76.1	16.0	65.4	—	157.5	97
	1958	59.2	33.6	82.8	—	175.6	97
ullman	1952[2]	66.3	16.0	49.7	—	132.0	254
	1953[2]	63.9	18.5	0.2	—	82.6	253
	1954	106.0	12.4	—	—	118.4	200
	1955	136.0	10.9	—	—	146.9	167
	1956	201.5	15.9	—	—	217.4	267
	1957[2]	70.2	15.8	—	0.1	86.1	150
	1958[2]	60.1	9.5	—	2.9	72.5	101

[1]Bluegill and redear sunfish.
[2]Lake was partially poisoned with rotenone during these years to return overcrowded forage fish populations to balanced conditions.

Pike Lake

Pike Lake (45 acres) contained speckled bullheads prior to the opening of the lake in 1953. This species survived two rotenone treatments of the lake and the watershed prior to stocking. However, when the lake was opened to fishing, good catches of sunfish, bass, and bullheads were made. During the summer of 1955 reproduction of sunfish had stopped and the population was overcrowded with bullheads, golden shiners, and small sunfish. This condition was accompanied by a corresponding decrease in the catch (Table 2).

Four marginal poisonings during September 1955 eliminated an average of 115 pounds per acre of intermediate-sized sunfish and approximately 22 pounds of harvestable bass. The kill of bass occurred during the last treatment and was attributed to sudden gusty winds that moved the rotenone rapidly into deeper waters. Since many of the bass had been eliminated, and since these treatments were ineffective in killing golden shiners and bullheads, sectional poisoning was used to correct the condition. A 3-acre section in the upper end of the lake and a 4-acre section adjacent to the dam were treated on October 4 and October 14, 1955, respectively. These areas were detoxified with potassium permanganate about 1 hour following the application of rotenone, to reduce the kill of bass that had moved into the poisoned areas.

These treatments removed an average of 134 pounds of unharvestable sunfish and 25 pounds of bass per acre. The kill of bullheads and golden shiners was less than 0.5 pound per acre. A decrease in the annual harvest of fish from Pike Lake during the following year was primarily attributed to the unfortunate kill of most of the adult bass. Although seining indicated the population was returning to balance during 1956, an increase in the annual harvest did not occur until the population became reestablished during the second year following partial poisoning (Table 2).

Cullman Lake

Cullman Lake (32 acres) contained a heavy population of green sunfish and yellow bullheads the first spring following the opening of the lake. From June 21, 1951, through December 31, 1951, the fishing pressure was 494 fisherman-trips per acre. Both heavy fishing pressure and competitive species contributed to an overcrowded population in the spring of 1952. Three marginal poisonings during June of that year killed 55 pounds of intermediate-sized sunfish per acre. Bluegill reproduction was sporadic in July 1952, and harvest by anglers continued to decline. An overcrowded fish population existed again in 1953 and the lake was marginally poisoned three times during November. This series of treatments killed an estimated 100 pounds of intermediate-sized sunfish per acre. On the basis of seining observations the population was in balance in 1954 and the harvest by anglers increased from 82.6 to 118.4 pounds per acre (Table 2).

The annual harvest by fishermen continued to increase in Cullman Lake until 1957 when the population again became overcrowded with sunfish. This change was probably due to heavy fishing pressure during 1956 when an average of 267 fishermen per acre took 217 pounds of fish. Four marginal poisoning treatments in September and October 195 killed 10 pounds per acre of intermediate-sized sunfish.

An unbalanced condition and a decrease in the catch continued during 1958. Competition from crappie, which were apparently stocked by uninformed sportsmen, contributed to the overcrowding. Marginal poisoning during September 1958 killed an estimated average of 97 pounds per acre of intermediate-sized sunfish and 8 pounds of intermediate-sized crappie but did not restore a balanced population in 1959.

CONCLUSIONS

Partial poisoning with rotenone is an effective and economical method of restoring balance to bass-bluegill-redear sunfish populations which are overcrowded with intermediate-sized bluegills and redear sunfish. Bullheads and/or crappie augment crowding in bluegill-redear sunfish populations and cause management problems that cannot be readily corrected by partial poisoning.

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Effects of Sodium Fluoride on Carp and Rainbow Trout

John M. Neuhold and William F. Sigler
Utah State University, Logan, Utah

ABSTRACT

The symptoms of acute fluoride intoxication in carp and rainbow trout include lethargy, violent and erratic movement, and death where there is partial or complete muscle contraction. Excessive mucus production associated with an increase in mucous cells in the epithelium of the head region and the gills also occurs. Changes in the electrophoretic pattern of the serum proteins in carp blood are evident. There is an increase in the fluoride concentration of the bones and a hypertrophy of the ultimobranchial gland. Rainbow trout embryos display initial symptoms similar to adult fish, including lethargy, violent movement, and tetany. Rupturing of the chorion by the embryo is attributed to violent movement during the onset of intoxication. Lethal doses and the sensitivities of fish to the toxin are dependent on several variables including size of fish, temperature of medium, and calcium and chloride concentration of the medium. It was demonstrated that there is an uptake of fluoride in muscle tissue, cancellous bone, and skeletal bone, and that uptake was increased when there was a rise in the fluoride concentration of the medium. The uptake of fluoride by the bone was via a second-order reaction and is assumed to be an enzymatic process. Proliferation of mucous cells in the epithelium of the gills and the head region is postulated to be instrumental in the excretion of fluoride from the body, and is considered an effective defense mechanism against fluoride intoxication. Hypertrophy of the ultimobranchial gland is thought to result from a deficiency in calcium induced by the effects of fluorides. The uptake of fluoride by the bone is a defense mechanism against fluoride intoxication and is postulated to occur with the elimination of fluoride from body circulation. This fluoride forms a stable mineral complex.

INTRODUCTION

The fluoridation of domestic water supplies to control dental caries has raised a number of questions, including the effect of fluorides on aquatic plants and animals. Fluorides in domestic water supplies may be derived from alcohol distilleries, phosphate plants, metal refining plants, and other industries which discharge effluents or gases containing fluorides into the atmosphere and surface waters. Aerial pollutants are leached from the atmosphere by rain and snow (Adams *et al.*, 1952; Gabovich, 1952) and into the aquatic environment. Another source of aquatic pollution is fluoride leached from superphosphates which have been applied as soil fertilizer.

Fluorides are introduced into the aquatic habitat from such natural sources as fluorite, apatite, cryolite, and sedimentary phosphate rocks. Gabovich (1952) reports that an estimated 15,117 tons of fluorides per year are carried by streams of the Ukranian Territory. The United States Geological Survey (1957) has shown that fluorides in water are common especially in western United States. Most of these waters had concentrations in the magnitude of tenths of a part per million, but a significant portion contained more than 1 p.p.m.

Areas of recent volcanic activity also a significant amounts of fluorides to wa Kobayashi (1951) reports wells in Ja which contain from 1.5 to 5.5 p.p.m. fluoric Our surveys indicate that hot springs a geysers of Yellowstone National Park cont from 25 to 50 p.p.m. fluorides. Firehole Ri and Madison River in Yellowstone Natio Park contain from 1 to 14 p.p.m. fluoric Water samples from Walker and Pyra Lakes in Nevada contain as much as 13 p.p fluorides.

Literature concerning the toxicity of fl rides to fish is rare. Ellis (1937) reports 1,(p.p.m. fluoride killed goldfish, in hard wa in 60 to 102 hours. In soft water morta time at 1,000 p.p.m. ranged from 12 to hours. DeRoos[1] reports that mortality tributable to fluorides occurred on goldfis 120 p.p.m. fluoride. Lee and Nilson (19 found that canned salmon and mackerel h high concentrations of fluorides in bo Fisher (1951) indicates some prepared fe containing fish meal contain relatively h concentrations of fluorides.

[1]DeRoos, Carolyn Clapp. (1957) The effect sodium fluoride on the weight gain and gills of common goldfish. M.S. Thesis, Utah State Univer Logan, Utah. 40 pp.

In order to assess the effect of fluorides on n, two fresh-water teleosts were selected as perimental subjects: the carp, *Cyprinus pio* Linnaeus, and the rainbow trout, *lmo gairdneri* Richardson. Both fish are yhaline. Between them they have a distri- tion in the Western States which covers st of the ecological niches from near-al- ne to sea level. In addition, both species e sport and commercial importance.

MATERIALS AND METHODS

The equipment for trout experiments con- ed of eighteen 20-gallon aquaria located refrigerated rooms which could be varied m 40° to 60° F. Each aquarium had both rescent and incandescent light. A sub- rged air line capped with a 1-inch carbo- dum stone supplied 30 cubic inches of air minute. Surface velocity was approxi- tely 0.1 foot per second with a complete face turnover every 30 to 40 seconds. Carp eriments were conducted in two 270-gallon one 150-gallon tanks. Lighting and aera- were accomplished in the same manner as the 20-gallon aquaria.

Rainbow trout eggs used for toxicity ex- iments were supported by a plastic screen hin a vertical plastic cylinder open at both ls. The bottom of the cylinder was vented, the air stone placed on top provided the essary energy for a vertical circulation of ter over the eggs. Experiments were tiated with eggs which had been held in F. water for 20 days after fertilization. ring experiments the eggs were in total kness.

Fluoride concentrations were maintained adding soluble sodium fluoride to the ter until it tested at the desired level. Since the acute intoxication studies were done soft water (calcium and magnesium were oved in a cation exchange column) only insignificant portion of the fluoride re- ined associated and suspended in the dium. The amount taken up by the fish that which may have been complexed h biological excretions also appeared to be ignificant since no difference could be cerned between the fluoride concentration he start and end of each experiment.

The water used was from Logan City, Utah, nicipal water supply which after softening the following analysis:

Material	p.p.m.
Total dissolved solids	251-297
Magnesium	0.0-0.3
Calcium	0.5-4.5
Potassium	4.3-5.8
Sodium	97-103
Sulfates	5.0-9.0
Bicarbonates	185-212
Carbonates	0.0
Chloride	5.0-12.0
Fluoride	0.10-0.20

Population densities

The proper densities at which to hold fish in the aquaria were determined empirically. Aquaria were initially overpopulated, oxygen consumption and the ammonia production were measured, and the effects on the fish noted. Numbers were then reduced until no significant change in the levels of oxygen and ammonia was detectable and until the fish displayed no abnormal antagonism to each other. These numbers were used as the maximum population densities for toxicity experiments.

The maximum allowable concentration of accumulated ammonia was 0.4 gram per square centimeter of surface (6.7 grams per liter) for carp and 0.1 gram per square centimeter of surface (3.33 grams per liter) for trout. Carbon dioxide was not accumulated, and there appeared to be no social antagonism at these levels. Temperature ranges were 60°-65° F. for carp and 50°-55° F. for trout. The actual rates of introduction of fish for the toxicity experiments were usually at 50 percent of the determined maximum allowable rates. This approaches the densities recommended by Doudoroff *et al.* (1951).

Rainbow trout eggs were held at densities of approximately 0.0037 gram per square centimeter of surface (0.25 gram per liter). No change in the oxygen concentration was observed. The ammonia concentration after 424 hours was less than 1 p.p.m. The temperatures at which rainbow trout eggs toxicity experiments were conducted ranged from 45° to 60° F. and bracketed the optimum temperature for development and survival.

Temperatures at which the toxicity experiments on rainbow trout were conducted were from 53° to 57° F. This temperature range agrees closely with the upper optimum growth

temperatures for *Salvelinus* sp. as reported by Brown (1957). Temperatures at which carp toxicity experiments were conducted were held from 60° to 70° F., a range which approached the optimum temperature for growth in carp as reported by Sigler (1958).

Chemical analysis of tissue

Both rainbow trout and carp were dissected to separate skeletal muscle, cancellous bone (represented by the opercular assemblies), and skeletal bone (represented by the vertebral column). After dissection the tissues were autoclaved for 2 minutes at 15 pounds to coagulate the protein. The samples were then wrapped in aluminum foil and frozen until analyzed. Since the samples were small with respect to the total amount of fluoride present, a micro-quantity fluoride determination technique was used (Nielsen, 1958). The values thus obtained had a precision of 5 percent in terms of gammas of fluoride.

This technique was also used to determine fluoride in water when samples were suspected of containing interfering ions. If interference was not a problem, water was analyzed by the application of the A.D.H.A. Megregian-Maier modifications as presented in *Water and Sewage Analysis* (Hach Chemical Company, Ames. Iowa). Determination of ammonia, oxygen, and carbon dioxide followed the techniques presented in Ellis *et al.* (1948). Blood samples were taken from fish by making a diagonal excision across the caudal peduncle, immediately posterior to the anal fin, to sever the caudal vein and artery. The blood was collected in a 3-inch plastic centrifuge tube and allowed to coagulate for 3 hours at room temperature. It was then centrifuged at 2,500 revolutions per minute for 20 minutes. The clear serum was syringed from the centrifuge tube, placed in 2-inch glass tubes which were sealed with polyethylene sheeting, and stored for periods not exceeding 3 days at 40° F.

Serum protein separations were made in a Spinco paper electrophoresis chamber for 14 hours. After development, the paper strips were analyzed in a Spinco Analytrol. The values obtained were in terms of percentage of total serum protein.

Histological examination

Tissue samples taken for histological preparation included the gills of rainbow tro and carp, the entire body of rainbow tro sac fry, and the esophagi of rainbow trou The techniques followed were those of Key and Willmer (1932) for the preparation gills to detect chloride-secreting cells. T population densities of epithelial muco cells were determined by counting their currence in 30 adjacent cells of a random selected gill filament, or in a medial secti of integumentary epithelium of the he region. The esophagi were prepared for t determination of fluoride effects on the th roid and ultimobranchial body which reputed to have parathyroid function in tr (Brown, 1957).

Experimental design and analysis

The toxicity experiments used two desig The first involved a gross division of conc trations of fluoride in magnitudes of 1 p.p.m. from 0 to 500 p.p.m. added as sodi fluoride. The concentrations were arranged random within the physical plant. The sa number of fish were used in each concent tion. This design was used to determine which concentrations complete mortal could be expected. The second design inclu concentrations which ranged between those which no mortality and complete mortal occurred. These concentrations were 0, 2, 7, 13, and 25 p.p.m. for the rainbow trout.

The responses of carp and of rainbow tr eggs were adequate in the gross ranges a no further subdivision of the concentrati was necessary. These experiments used analysis of the probit responses and follow the techniques presented by Finney (195 and Goulden (1952). Both the sensitivity the fish to toxin and the L.C. 50 (lethal c centration to 50 percent of the fish) were timated at the 95 percent confidence le Rainbow trout egg toxicity experiments f lowed a randomized block design in wh the temperatures were blocked and the c centrations distributed at random within blocks. The analyses from these experime also followed the probit analysis technique

The first calcium-fluoride relationship periment was conducted on the basis of t simple factorial designs. The first was a 2 6 in which the fluoride concentrations wer and 25 p.p.m., and the calcium concentrati were 0, 1, 2, 3, 4, and 5 p.p.m. The fluor was added as sodium fluoride and the calci

calcium fluoride. The fluoride of calcium as added to the water in the situation where e amount of calcium required was less an the solubility of calcium fluoride. Ad- tional increments of fluoride were added sodium fluoride.

The second experiment was a 3 by 6 fac- rial in which the fluoride concentrations re 0, 7, and 13 p.p.m., and the calcium ncentrations were 0, 2, 4, 7, 13, and 25 .m. The fluoride was added as sodium oride and the calcium as calcium hydrox- . The constituents were dissolved with the of carbon dioxide as dry ice, which was led to the water to provide a slight change the pH. After the constituents were dis- ved the water was agitated to drive off the cess carbon dioxide. This changed the pH m 8.0 to 7.9. This slight change in pH was ributed to a slight persistence of carbonic id in solution. These experiments involved probit analysis of response to the log meta- ter of the ratio of fluoride to calcium. The ults of the two experiments were combined the analysis. In all of the toxicity experi- nts the units of measurement included the sponse of the fish, or the eggs, in terms of rcentage mortality.

To determine the relationship of fish size fluoride concentration in terms of mortal- , another simple factorial was used. Carp this experiment were arranged in length oups. The design was a 3 by 5 factorial in ich three concentrations of fluorides were mbined with five length groups. Concentra- ns of fluorides were 250, 325, and 500 .m. The 2-inch length groups ranged from to 14 inches. Since the numbers of fish per gth group per concentration varied, a torial with disproportionate subclass mbers was used (Snedecor, 1946).

LETHAL DOSES OF FLUORIDE

Acute symptomology

Symptoms of acute fluorosis displayed by carp and rainbow trout included apathy and anorexia. The onset of these symptoms was dependent on fluoride concentration and time of exposure. Apathy and anorexia were followed by a period of violent, sporadic movement, loss of equilibrium, and finally death. The near-death symptoms were characterized by the loss of equilibrium and muscle tremors, especially in the dorsal and caudal peduncle regions. Fish died in a state of partial or total muscle contraction. During the period in which these symptoms were displayed, the fish appeared to secrete an excessive amount of mucus, especially in the higher range of fluorides.

Changes in serum proteins also occurred (Table 1). These determinations were made on carp displaying muscle tremors and those displaying no symptoms. Proteins designated as 2, 5, and 7 showed significant differences. The fish which displayed muscle tremors had a reduction in the level of protein 2 and an increase in the levels of proteins 5 and 7. Protein 4 was significant at the 90 percent level of confidence. This result might be interpreted as a change in protein level. The change indicates that it decreases with the onset of tremors.

Rainbow trout embryos, which died within the egg, displayed symptoms similar to those of adult fish. Violent movement often ruptured the vitelline membrane, and the embryo succumbed *in vitro*. If the membrane was not ruptured the embryo died *in vivo*. Death of the embryo was usually concurrent with coagulation of the yolk protein. If the vitelline membrane ruptured, the embryo invariably left the egg sac headfirst. Not infrequently, embryos were caught in the membrane. If these fish lived, they often had deformed spines.

BLE 1.—*Mean percentage serum protein levels from normal carp and carp displaying symptoms of fluo- ide intoxication determined by paper electrophoresis analysis*

Symptom	Protein designation								
	1	2	3	4	5	6	7	8	9
any	3.41	4.26	5.57	2.44	35.47	10.96	12.91	9.81	11.11
tetany	4.94	8.22	5.37	3.24	27.25	10.68	8.74	9.32	11.17
ference	−1.53	+3.96*	+0.20	−0.80	+8.22*	+0.28	+4.17*	+0.49	−0.06

Significant at the 95 percent level of confidence.

The length of time it takes eggs to hatch in fluoridated water varies with the concentration. Eggs hatch earlier in high concentrations but are not as advanced in development. An analysis of variance of the hatching time of 400 rainbow trout eggs subjected to 0, 100, 200, and 300 p.p.m. of fluoride indicates that a significant linear regression exists in hatching time against concentration.

Rainbow trout

The toxicity of fluorides to rainbow trout was determined on fish ranging in length from 4 to 8 inches when the water contained less than 3 p.p.m. of calcium or magnesium. At 55° F. the L.C. 50 varied between 2.7 and 4.7 p.p.m. fluoride (95 percent confidence level) in a 480-hour experiment with the last recorded mortality occurring at 218 hours. The sensitivity (the slope of the regression formula) of the fish to concentration of fluorides was between 2.43 and 4.01 probits of response to one unit change in the log concentration of the toxin at the 95 percent level of confidence. This relationship held to the formula

$$Y = 3.19 + 3.27X$$

where Y is the response in probits and X is the log of the fluoride concentration (Figure 1).

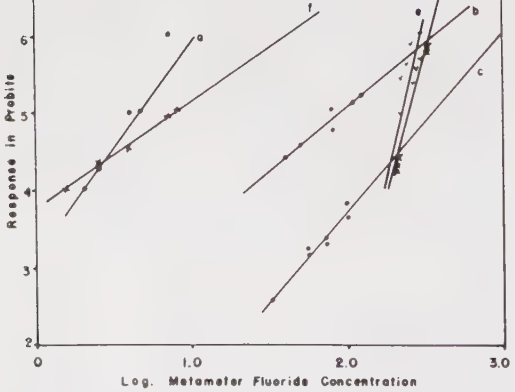

FIGURE 1.—The response of rainbow trout, carp, and rainbow trout eggs to concentrations of fluoride: (a) rainbow trout at 55° F.; (b) carp at 65° F.; (c) rainbow trout eggs at 46° F.; (d) rainbow trout eggs at 55° F.; (e) rainbow trout eggs at 60° F.; (f) rainbow trout from hatching to the absorption of the egg sac at 60° F.

Carp

The toxicity of fluorides to carp was determined on fish ranging in length from 4 to 14 inches. The calcium and magnesium concentrations were below 3 p.p.m. At temperatures ranging between 65° and 75° F., the L.C. 50 was between 75 and 91 p.p.m. fluoride (95 percent confidence level). The sensitivity was between 1.92 and 1.94 probits response per unit change in the log metameter (95 percent confidence level). The relationship between the probits of response and the log metameter of the fluoride (Figure 1) followed the formula, $Y = 1.93X - 1.31$.

The size of carp influenced the length of time required to produce death at any concentration, but did not determine the L.C. 50 (Table 2). As the size of fish increased, a longer time elapsed before mortality occurred at any concentration.

TABLE 2.—*Mean number of hours before death of carp in varying length groups at different concentrations of fluoride*[1]

Length group (inches)[2]	Concentration (p.p.m.)[2]			Mean
	250	325	500	
4-5	110.67	112.95	35.01	86.2
6-7	121.25	123.53	45.59	96.7
8-9	124.40	126.68	48.74	99.9
10-11	171.34	173.62	95.68	146.8
12-13	149.41	151.69	73.75	124.9
Mean	135.41	137.69	59.75	—

[1]The values are corrected for unequal subclass numbers (Snedecor, 1946).
[2]Significant at the 99 percent level of confidence.

Rainbow trout eggs and fry

Rainbow trout eggs at identical stages of development were tested in water and various temperatures with calcium and magnesium concentrations of less than 3 p.p.m. At 46° F. the L.C. 50 was between 222 and 273 p.p.m. fluoride (424 hours); at 55° F. it was between 242 and 261 p.p.m. (214 hours); and at 60° F. it was between 237 and 281 p.p.m. (167 hours). All estimates are at the 95 per cent confidence level.

The sensitivities were established between 1.88 and 2.16, 7.14 and 7.24, and 10.65 and 10.97 probits of response per unit of the log metameter of the fluoride for 46° F., 55° F. and 60° F., respectively. The relationship between the log metameter of the fluoride and

e probits of response for the three tempera-
res are expressed by the following formulae
igure 1): 46° F., $Y = 2.02X - 0.17$; 55°
$Y = 7.19X - 12.36$; and 60° F., $Y =$
$.81X - 21.08$.

Another experiment with rainbow trout
bryos and the fry extending to the time of
lk-sac absorption was conducted at 60° F.
r 825 hours. The L.C. 50 was between 61
d 85.3 p.p.m. fluoride, and the sensitivity
s between 1.28 and 1.40 probits of re-
onse per unit change in the log metameter
5 percent confidence limit). The relation-
p between the log metameter and the pro-
s of response (Figure 1) is expressed by
formula, $Y = 1.34X - 2.52$.

FACTORS AFFECTING FLUORIDE TOXICITY

Temperature

Temperature appears to have an effect on
h the sensitivity and the L.C. 50. An in-
ease in the temperature resulted in an in-
ease in the sensitivity from 2.02 at 46° F. to
.81 at 60° F. (Figure 2). This experiment
s conducted on rainbow trout eggs and pro-
essed until all the eggs hatched or re-
onded to the toxin. The L.C. 50 also in-
eased from 246 p.p.m. at 46° F. to 251
p.m. fluoride at 60° F. (Figure 2). A test of
e hypothesis that the variances of the L.C.
's or the sensitivities are equal (Dixon and
assey, 1951) indicates that significant dif-

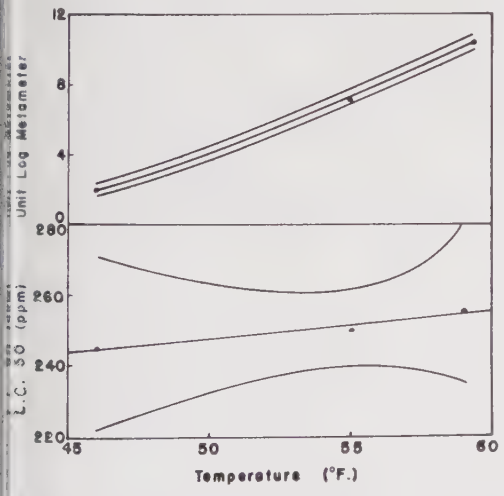

FIGURE 2.—The empirical relationship between
nsitivity and temperature (upper) and the L.C.
and temperature (lower) of rainbow trout eggs.

ferences exist, or that the variances at different temperatures were sufficiently different to consider them from separate populations.

Calcium

The relationship between the concentrations of calcium and fluoride ions and the L.C. 50 of rainbow trout subjected to varying combinations of calcium and fluoride was determined by plotting the log of the ratio of fluoride to calcium against the probit of responses to the varying combination of calcium and fluoride. A straight line relationship from which the L.C. 50 can be determined was found (Figure 3). The L.C. 50 was determined between 1.01

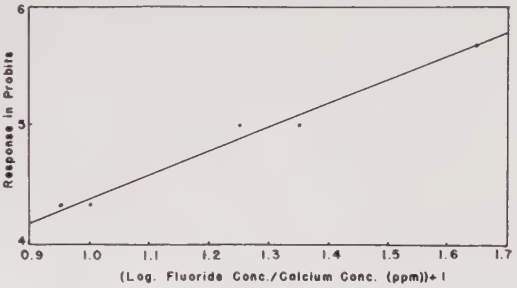

FIGURE 3.—The response of rainbow trout to combinations of fluoride and calcium in the medium (expressed as the ratio between fluoride and calcium).

and 4.22 [fluoride] / [calcium] at the 95 percent confidence level. The sensitivity of the rainbow trout to the ratio of fluoride to calcium was between 1.71 and 2.35 probits of response per unit change in the log of the ratio. The relationship between the response and the log of the fluoride/calcium ratio (Figure 3) is expressed by the formula,

$$Y = 2.33 - 2.03X$$

where Y is the response in probits and X is the logarithm of the ratio between the fluoride concentration and the calcium ion concentration plus one unit characteristic.

Chloride

The effect of chloride on the toxicity of fluoride was tested with the mosquitofish, *Gambusia affinis* (Baird and Girard). The toxicity of a given level of fluoride was increased when the total anion normality was increased by the addition of sodium chloride. At 500 p.p.m. fluoride the mortality time for

50 percent of the fish was 14 hours, and 100 percent was 19 hours. When the total anion normality was increased from 0.026 (fluoride at 500 p.p.m.) to 0.26 by the addition of sodium chloride the mortality times were decreased to 30 minutes for 50 percent of the fish and 1 hour for 100 percent. The controls with a total anion normality of 0.26 introduced as sodium chloride produced no apparent ill effects.

FLUORIDE UPTAKE

Uptake in muscle tissue

Variation in the amounts of fluoride in muscle tissues was high in both carp and rainbow trout. This variation was due in part to an inability to extract integumentary bones from the muscle samples. Since the bones held high concentrations of fluorides, any fluctuation in the amount of bone tissue in the sample caused very significant variations in the apparent fluoride content of the muscle tissues. The values obtained for the muscle tissues could, however, be lumped into high and low medium fluoride concentration categories, and the variance produced by the two categories could be demonstrated. Since low levels of fluorides in the water produced a concentration in the muscle tissues of 2.95 p.p.m. and the high levels produced 20.83 p.p.m., it is concluded that the fluoride concentration in the muscle tissue increases with an increase in the fluoride concentration in the medium (99 percent confidence level).

Uptake in osseous tissue

Fluoride uptake in the osseous tissues is a function of time and fluoride concentration in the medium. Analysis of the data indicates that concentration in the medium has the greater effect on the fluoride concentration in the bone. Cancellous bones from the head region of both rainbow trout which lived and died during the experiments were analyzed. When the mean rate of fluoride uptake by bone per hour is plotted against concentration in the medium, a quartic polynomial relationship results (Figure 4A). A similar relationship existed for both the cancellous and skeletal bones of rainbow trout (Table 3).

The bone samples from these fish were taken at the termination of the experiment. This procedure secured samples from fish that had died from the toxin and from fish that lived to the termination of the experiment. Use of two types of samples could introduce a source of variation if the rates of uptake from both types were analyzed together. This variation could be eliminated if one or the other types were analyzed separately (Figure 4B).

Since the fluoride in the medium was the only source of fluoride, it could have been an index to the fluoride in the fish bone. On this assumption, the fluoride concentration of the medium becomes the concentration of one of the reactants in the reaction in which fluoride

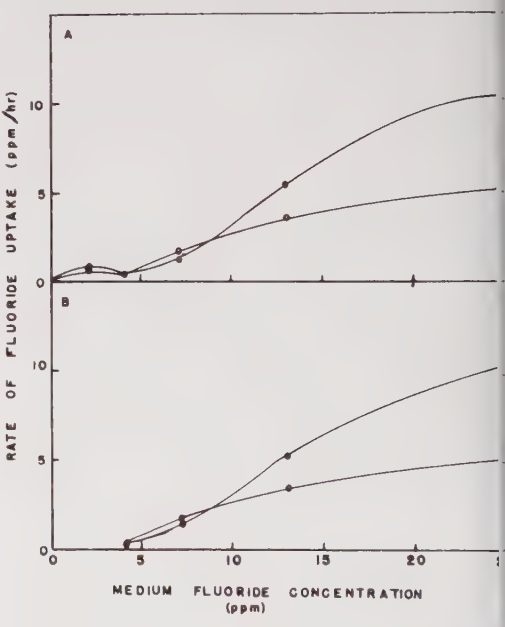

FIGURE 4.—The empirical relationships between the rate of fluoride uptake and the medium concentration of fluoride for cancellous and skeletal bone of rainbow trout (circles represent skeletal bone and dots represent cancellous bone): A. for all fish undergoing experimentation; B. for only fish that succumbed to fluoride intoxication during the experiment.

is deposited in the bone, and the rate of fluoride uptake becomes the velocity of the formation of products in the same reaction. A double reciprocal plot of the type presented by Lineweaver and Burk (1934) resulted in significant (at the 99 percent level of confidence) linear regressions for cancellous and skeletal bones in both the rainbow trout and the carp.

TABLE 3.—*Relationships of the reciprocal of fluoride uptake in various bones to the reciprocal of the fluoride concentration in the medium*

Species	Bone	Formula[1]	Illustration
Rainbow trout	Cancellous	$Y = 0.003 + 1.979X$	Fig. 5a
Rainbow trout	Skeletal	$Y = 0.014 + 1.431X$	Fig. 5b
Carp	Cancellous	$Y = 0.004 + 12.751X$	Fig. 5c
Carp	Skeletal	$Y = 0.023 + 25.520X$	Fig. 5d

[1]Where Y is $1/v$ and X is $1/[S]$.

The relationships are expressed by the formulae tabulated in Table 3 and illustrated in Figure 5. These relationships are characteristic of second-order reactions. Since they occur in a biological system they could be assumed to be enzymatic reactions of the type,

$$[E] + [S] \rightleftharpoons [ES] \rightleftharpoons [P] + [E]$$

where $[E]$ is the enzyme concentration, $[S]$ is the fluoride concentration, $[ES]$ is the enzyme-fluoride complex, and $[P]$ is the product concentration. The formulae of Table 3 would then assume the Lineweaver-Burk form,

$$1/v = (Km/Vmax)\ (1/[S]) + 1/Vmax$$

where v is the velocity of the formation of the products, Km is the Michaelis constant, $Vmax$ is the maximum velocity, and $[S]$ is the fluoride concentration.

Fish from natural populations offered another opportunity to check the fluoride uptake by the bones. Brown trout from the Firehole River in Yellowstone National Park have a tendency to accumulate fluoride in the bones. This river contains from 1 to 14 p.p.m. fluorides. The fish collected ranged in age from less than 1 to 3 years and from 142 to 400 millimeters in total length.

Regression of the fluoride concentration in the bone on the length of the fish proved to be significantly linear at the 95 percent level of confidence. This relationship (Figure 6) for the cancellous bone is expressed by the formula, $Y = 1.518X + 328$, and the relationship for the skeletal bone by the formula, $Y = 5.501X - 471$, where Y is the concentration of the fluoride in the bone in parts per million and X is the length of the fish in millimeters.

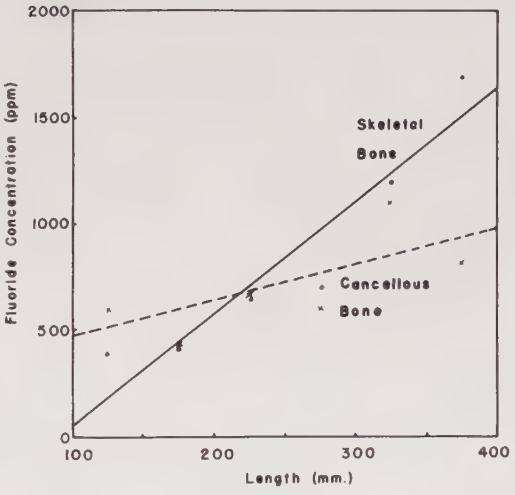

FIGURE 6.—The relationship between the fluoride concentration in cancellous and skeletal bone and length of brown trout from the Firehole River, Yellowstone National Park.

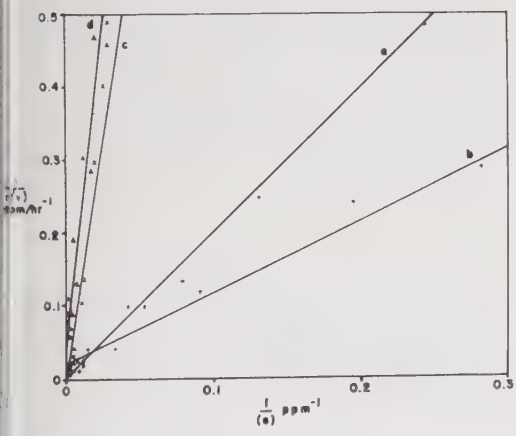

FIGURE 5.—The relationships between the reciprocals of the rates of uptake and the reciprocals of the medium concentration of fluoride for: (a) rainbow trout cancellous bone; (b) rainbow trout skeletal bone; (c) carp cancellous bone; (d) carp skeletal bone.

Uptake by rainbow trout eggs

Data on uptake of fluoride by rainbow trout eggs were treated similarly to bone data. Since the analysis for fluoride was on a group of eggs, mortality time was the average time for each concentration. The analysis was on both eggs and freshly hatched fry combined since it was difficult to separate the eggs that died from the toxin and the fry that died shortly after hatching in the toxin.

Significant linearity (99 percent confidence level) was observed in this regression. The relationship (Figure 7) between $1/v$ and $1/[S]$ is expressed by the formula, $Y =$

$325.35X - 0.51$, and is similar to those for fluoride uptake in the bones except that the Y intercept is a negative value.

Histology

Increasing the concentration of fluoride in the medium appears to have an effect on the population of mucous cells in the epithelium of the gill filaments. In rainbow trout an increase of mucous cell density from 0.31 at 0 p.p.m. fluoride to 0.52 at 25 p.p.m. fluoride was observed (Figure 8). The linearity of this relationship was significant at the 99 percent level of confidence and followed the formula, $Y = 0.25X + 9.47$, where Y is the count of mucous cells per 30 epithelial cells and X is the concentration of fluorides in the medium in parts per million.

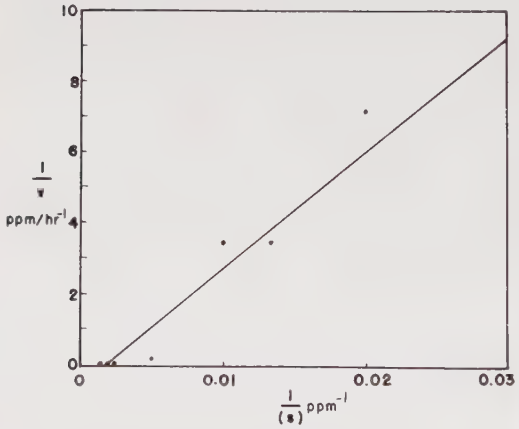

FIGURE 7.—Relationship between the reciprocals of the rate of uptake and the medium fluoride concentration for rainbow trout eggs.

The epithelial tissue in the head region of rainbow trout fry subjected to two ranges of fluoride concentrations (0 to 25 p.p.m. and 250 to 335 p.p.m.) also indicated an increase in the mucous cells with an increase in the fluoride concentration. The tissue upon which determinations were made was integumentary epithelial tissue located dorsally between the eyes. The population density of the mucous cells ranged from 0.367 in 0 p.p.m. fluoride to 0.867 in 335 p.p.m. fluoride (Figure 8). The relationship between the mucous cell density and the fluoride concentration of the medium showed significant (99 percent level of confidence) curvilinearity. Since the

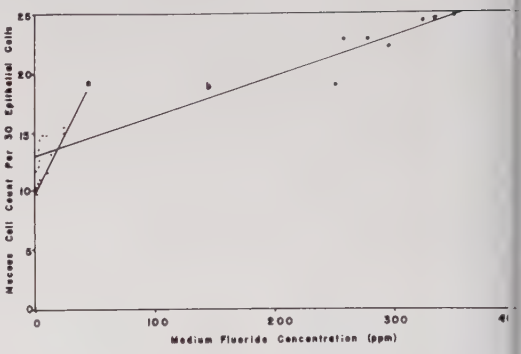

FIGURE 8.—Relationship between the mucous cell count per 30 epithelial cells and the medium fluoride concentration from (a) the gill filament and (b) the inter-ocular integument of rainbow trout.

fluoride concentrations were not at equal increments but rather at two widely spaced portions of the range, no attempt was made to determine the extent of curvilinearity, but there appeared to be a quadratic polynomial relationship.

In addition to changes in the epithelial tissues, changes also appeared to occur in one of the glands. Hypertrophy of the ultimobranchial gland (homologous to the parathyroids in mammals) appeared to occur in fish exposed to higher concentrations of fluorides. This observation is based on comparison with glands of fish maintained as controls (Figure 9).

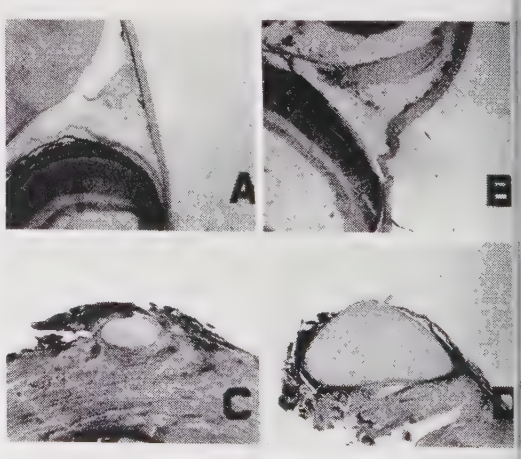

FIGURE 9.—Photomicrographs of A, integumentary epithelium of rainbow trout from 0 p.p.m. fluoride x 150; B, integumentary epithelium of rainbow trout from 250 p.p.m. fluoride x 150; C, ultitimobranchial gland of rainbow trout from 0 p.p.m. fluoride x 400; D, ultimobranchial gland of rainbow trout from p.p.m. fluoride x 400.

EFFECTS OF THE TOXIN ON THE FISH

The symptoms of acute toxicity of fluorides to rainbow trout and carp are similar to those described by DeRoos for goldfish. The general lethargy, violent movements, and tetanic-like death were identical in both studies. The lethargy observed for the carp and rainbow trout, however, appeared to be a function of intoxication rather than a function of osmotic pressure differentials as stated by DeRoos. This reaction is ascribed to observations in which both the carp and the rainbow trout reacted identically whether or not they were "tempered" to the osmotic concentrations of the fluoride. The symptoms of lethargy and violent, erratic movement are analagous to some of those displayed by higher vertebrates (Greenwood, 1956).

The embryos of rainbow trout displayed symptoms similar to those of larger fish. This implies that fluoride ions transgress the chorion and are made available to the embryo. Shanklin (1954) demonstrated that fluoride has the effect of reversing the calcium flux across the chorion of *Fundulus* eggs and of building up a concentration of fluoride within the egg.

Ellis *et al.* (1948) indicate that fish eggs subjected to 1.5 p.p.m. fluoride are delayed from 7 to 10 days in hatching beyond comparable eggs in water containing no fluorides. For a higher range of concentration rainbow trout eggs displayed a very significant negative slope for the regression of hatching time on concentration of fluorides. The earlier hatching is probably the result of violent contortions of the embryos intoxicated with fluorides but could be a result of structural disruption of the proteins of the vitelline membrane and the chorion.

Proliferation of mucous cells in the epithelium of fish subjected to fluorides appears to corroborate the subjective observation that there is an increased secretion of mucus by such fish.

The fact that the fluoride concentration in bones increases with concentration in the medium was not surprising since this phenomenon has long been established with higher vertebrates. The experiments performed to establish this in carp and rainbow trout, however, fell somewhat short of direct demonstration. Since the bones taken for analysis were from fish that died as a result of acute intoxication or from fish that lived past the critical acute toxicity point of the experiment, two factors tended to confound each other in the analysis: (1) the period of time each fish was subjected to a given concentration of fluoride and (2) the concentration of fluoride to which each fish was subjected.

The concentration of fluoride in the bones increases with the concentration of fluorides in the medium via a second-order reaction. Since this reaction is in a biological system, it is assumed to be an enzyme-catalyzed reaction. Fluoride, in order to be placed in a position to be absorbed by the bone under the simplest possible conditions, must pass through several physiological phases. It must first transgress the gill or integumentary epithelium into the blood stream which carries it to the bone where it must transgress the capillary walls into the osteo interstices.

Similar observations were made on the rainbow trout eggs (Figure 7). This work was confined to an analysis of fluoride content of the entire egg rather than any specific part. The fluoride must transgress the chorion in an activated fashion, *i.e.*, it must be actively transported across the membrane, presumably by an enzymic reaction. Shanklin (1954) made similar observations on the uptake of fluoride by *Fundulus* eggs.

Another point that requires discussion is the difference of fluoride uptake by the skeletal and cancellous bones. The reciprocal of the velocity of fluoride uptake by the bones changes 1.979 units per unit change in the reciprocal of the fluoride concentration in the medium in the cancellous bones and 1.431 in skeletal bones of rainbow trout. This difference in the slopes is believed to be of small significance. The bones of carp displayed an almost two-fold difference between the slopes of their relationships. The cancellous bones had a slope of 12.7 and the skeletal bones 25.5. This difference is probably related to differences in the amount of non-osseous material which remained on the bones after they were cleaned.

Fluorides tend to occur in fish blood in unassociated, ionic form and associated with another ion or molecule. Because of its high electro-negativity the fluoride ion is more likely to be associated with the electro-positive elements such as calcium and magnesium ions. Gurd (1954) indicated sodium fluoride changes the isoionic point of human serum

albumin to an extent more than twice the change produced by sodium chloride. This indicates fluoride is bound to the protein. A change in the isoionic point of the protein would result in a changed electrophoretic pattern. This appeared to happen to several of the proteins in the carp serum we tested (Table 1).

The determination of acute lethal concentrations of fluoride is dependent on an accurate description of symptoms. The symptoms presented here are sufficiently accurate to separate the fish that die from acute intoxication and from other causes. The time to produce acute symptoms varies with the concentration. An evaluation of the lethal concentrations or the sensitivity cannot be reached, therefore, until all fish exhibiting the symptoms defined for acute intoxication have succumbed. For this reason a specific time interval for the experimentation was not incorporated into the design. The length of the experiment is dependent on the time required for the last of the fish in the group to succumb to the effects of acute intoxication. Thus, in our definition of acute intoxication, a subjective interpretation of the point when the last of the fish dies must be made.

The lethal doses and the sensitivities presented here are valid only for the conditions under which the experiments were conducted. A number of variables were shown to have effects on either the sensitivity, the L.C. 50, or the length of the experiment.

The size of the fish has a very definite relation to the length of the experiment as reflected by the time required for the fish to succumb to the toxin (Table 2). This, however, has no apparent effect on the L.C. 50 or the sensitivity in the probit analysis.

Temperature has a definite effect on the sensitivity as well as the length of mortality time for rainbow trout eggs (Figure 2). Both of these observations may be attributable to differences in metabolic rates of small and large fish of the same species. The same is true for temperature differences with the higher temperatures tending to increase the rate of metabolism of fish eggs (Brown, 1957). Our findings indicate that the sensitivity of the eggs to the toxin increased with a rise in temperature. This indicates that the mortality due to fluoride intoxication occurred more completely in a given concentration, or that all the mortality that resulted from fluoride intoxication occurred within a narrower range of fluoride concentrations. The L.C. 50, on the other hand, increased slightly, but significantly, as temperature increased. This finding appears somewhat paradoxical and requires further investigation.

The calcium concentration of the medium seems to reduce the effectiveness of the toxin (Figure 3). The high affinity fluoride has for calcium tends to reduce the effective calcium concentration in the body especially since some of the biochemical reactions require calcium as an activator. The added calcium in the medium provides a source for replenishment of the calcium required to maintain body functions. The chloride concentration of the medium appears to make the fluoride more toxic when the two are included together in the medium.

DEFENSE MECHANISMS

The defense mechanism against fluoride intoxication is essentially fluoride elimination which can be accomplished by excretion either through the kidney or the respiratory epithelium. Fluoride may produce many of its toxic effects because it inhibits enzymes which require calcium and magnesium for their activity (Whittaker[2]). The elimination of fluoride, therefore, is instrumental in the alleviation of enzymic inhibition, and can be accomplished by incorporation of the fluoride into the bone as a stable mineral complex (Shupe *et al.*, 1955).

DeRoos discusses the similarities between epithelial cells of fish subjected to fluoride and fish subjected to chlorides. Bevelander (1935) believes that the chloride-secreting cells may be modified mucous cells and that chloride may be secreted (associated with the mucin). The increase of the density of the mucous cells in both the gills and the integumentary epithelium of the head region in rainbow trout (Figures 8 and 9) is similar to that noted in goldfish (DeRoos). The mucous cells in rainbow trout and goldfish subjected to fluorides appear to have morphological similarities to the chloride-secreting cells in *Fundulus* and may function as fluoride-secreting cells.

[2]Whittaker, V. P. (1954) Fluorides as enzyme inhibitors. Symposium on fluorides. Univ. of Cincinnati, May 11, 1954. (Mimeo.)

The apparent hypertrophy of the ultimobranchial gland in the rainbow trout that were subjected to fluorides and the display of tetany just prior to mortality are relatively good indications of a calcium deficiency. Turner (1955) indicated tetany can be the result of calcium deficiency in body fluids and that hypertrophy of the parathyroid (ultimobranchial in fish) is often a result. Fluoride tends to form stable complexes with dissolved calcium in the blood and thereby reduces the ionic calcium concentration. It will also react with calcium serving as activators of certain enzyme systems. Fluoride apparently replaces the hydroxyl and bicarbonate groups in the surface of the mineral face of the bones (Neuman *et al.*, 1950) and consequently forms a very stable mineral complex with calcium. Thus, calcium becomes less available for mobilization from the bone. All these factors apparently combine to effect the hypertrophy of the ultimobranchial body in fish. It is significant that calcium in the medium has the effect of delaying the symptoms and apparently acts as a reservoir for body calcium.

The formation of a stable mineral complex with fluoride in the bone would act as a means of eliminating fluoride as well as calcium from systemic circulation, and it was noted that the uptake increases with an increase in the substrate concentration (Figure 5). This response is characteristic of a second-order reaction. If the mucous cells in the epithelium are assumed to act as a fluoride-secreting mechanism, and if their proliferation is assumed to be a function of the fluoride concentration in the blood, the tendency would be toward an increased concentration of blood fluorides with increased concentration of medium fluorides. The effect on the velocity of the fluoride uptake on the bones would then be similar to the relationships presented here.

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SHORT PAPERS AND NOTES

The Appearance of Pink Salmon, *Oncorhynchus gorbuscha* (Walbaum), in Lake Superior

Two salmonid fishes were caught in the fall of 1959 by two anglers in or just above the mouths of two Minnesota streams flowing into Lake Superior and were turned over to the Minnesota Department of Conservation. They were identified as pink salmon, *Oncorhynchus gorbuscha* (Walbaum), and have been deposited in the collections of the University of Minnesota. One fish was caught by Willard J. Hegard, September 11, 1959, in the mouth of the Cross River in Cook County and the other by William A. Vancalberg, September 19, 1959, in the Sucker River just below Highway 61 bridge in St. Louis County. These streams support substantial runs of both brown trout *(Salmo trutta)* and rainbow trout *(Salmo gairdneri)* from Lake Superior.

One of the fishes had been eviscerated before it was turned over to the Department of Conservation and measured 19 inches total length. The other fish was intact and measured 19½ inches total length. Both were males and the non-eviscerated specimen had well developed testes. Both were distinctly humped anterior to the dorsal fin and had slightly hooked upper jaws indicating that they had started to develop the secondary sexual characters which Davidson (1935) states appear in the last 35 to 45 days of their life cycle. Both of the fish had the characteristic markings of the pink salmon. They were well marked dorsally with relatively large dark spots and had the characteristic large rectangular spots on the upper part of the deeply forked caudal fin. One had 212 scale rows and the other had 210 scale rows passing through the lateral line. The identification was verified by Dr. Frederick A. Davidson, formerly of the U. S. Fish and Wildlife Service, who saw the fish soon after they were deposited at the University.

The capture of two mature pink salmon at different places in the Lake Superior drainage adds to the number of new fishes which have recently appeared in Lake Superior (Eddy and Underhill, 1959) and raises an interesting problem concerning their origin and probability of survival of a population. The completion of the life cycle of the pink salmon in fresh water is unusual. It has been termed an "obligatory anadromous species" by Rounsefell (1958) which he defines as those species which "either cannot reproduce, or cannot do so with sufficient success to maintain a natural population, without residing for some time in a marine environment." Rounsefell also pointed out that no natural fresh-water populations of pink salmon are known to exist, and that it exhibits the highest degree of anadromy of various species of the North American salmonids. Under normal conditions the pink salmon is known to spawn primarily in rivers, with the resulting fry entering the sea soon after development to the free-swimming stage.

Inquiries concerning the possible origin of these salmon were made to the Province of Ontario, the several states bordering Lake Superior, and the U. S. Fish and Wildlife Service. Only the Ontario Department of Lands and Forests gave any information concerning the possible origin of these fish. They stated that in 1955-1956 eyed eggs of pink salmon were hatched in the Port Arthur Hatchery located on Thunder Bay in Ontario about 40 miles north of the Minnesota border. These eggs were collected from the Skeena River in British Columbia during the fall of 1955.

About 518,000 of the resulting fry were subsequently introduced into Goose Creek, a tributary of Hudson Bay, and 221,000 fry were raised to fingerlings for introduction into the Hudson Bay drainage. Provincial authorities suggested that some small accidental escapement into Lake Superior may have occurred from the hatchery during rearing. It was further learned from Richard Ryder, of the Ontario Department of Lands and Forests, that in the process of transferring the fingerling salmon from the Port Arthur Hatchery to a seaplane, there was a known escapement of probably less than one hundred fingerlings into Thunder Bay of Lake Superior.

A number of attempts have been made to introduce salmon into Lake Superior but most of these attempts were with the chinook salmon and no permanent survival resulted (Eddy and Surber, 1947). Minnesota records show introduction of chinook salmon in Lake Superior during the period of 1911 through 1922. The U. S. Bureau of Fisheries introduced chinook salmon into Lake Superior and into the St. Louis River at various times prior to 1903. Many times these were listed as California salmon but a check of the records indicates that they were chinook salmon. Edward Schneberger of Wisconsin in correspondence states that the Wisconsin Conservation Department planted an unknown species of Pacific salmon during the period of 1920-1924. A. B. Cook states in a letter that the State of Michigan introduced chinook salmon in 1870. Nowhere have there been any records of intentional introduction of pink salmon into Lake Superior.

It is improbable that the pink salmon caught in 1959 resulted from any salmon introduced in the period of 1870 to 1922. It is unlikely that even a small population could have gone undetected for 60 years, especially in view of the large amount of commercial gill netting that has been carried on during that time. The pink salmon caught in 1959 were most probably derived from the 1955 brood year which escaped from the Port Arthur Hatchery operations, or were progeny of that group.

Acetate impressions of the scales from the two males caught in 1959 were made and showed only a single annulus. Scale impressions were submitted to Dr. William Ricker of the Fisheries Research Board of Canada, who confirmed these determinations. The captured fish with a single annulus were 2 years old and would be the progeny of brood salmon spawning in the fall of 1957. Gilbert (1913) and Davidson (1934) both determined that pink salmon normally spawn at 2 years of age.

Since there is no evidence of any introduction or accidental escapement of 1957 brood salmon into Lake Superior, the only reasonable alternative is that some of the salmon hatched from the Canadian eggs of the 1955 brood year escaped into Lake Superior, and spawned successfully in the fall of 1957; and that at least two individuals, which were caught by anglers as they were maturing for the 1959 spawning season, survived.

The scale margins showed evidence o erosion which Ricker states is characteristi of maturing pink salmon. The pelvic regio and the lower lobe of the caudal fin of one o the males also showed considerable abrasio which is characteristic of breeding males.

It is unfortunate that no females have bee observed because the degree of developmen of the ovaries would have provided more use ful information on spawning. The stream entering Lake Superior from the Minneso shore support a sport fishery for both lake run rainbow and brown trout. It is highl probable that other salmon have been caugh but did not arouse sufficient curiosity for th angler to report them. This oversight could b especially true for females which would nc exhibit a pronounced hump and whose colo ation might pass for an odd brown trout.

The only available facts are that two pin salmon, 2 years old, were caught by angler in or near the mouths of two streams flowin into Lake Superior. The only probable origi seems to be indirectly from an escapement c pink salmon from the 1955 brood at the Po Arthur Hatchery in 1956. If this is the source some of these salmon completed their lif cycle in Lake Superior and spawned succes fully in the fall of 1957. The survival an growth of salmon from eggs spawned in th fall of 1957 resulted in at least two male which reached maturity and were caught b anglers in 1959.

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Robert E. Schumacher
Minnesota Department of Conservation
St. Paul, Minnesota

Samuel Eddy
University of Minnesota
Minneapolis, Minnesota

Length Shrinkage of Yellowtail Flounder between Live and Landed Condition[1]

In fish-tagging experiments it is sometimes found that lengths of early recaptures are less than lengths recorded at time of tagging. This difference has been observed in marking experiments on yellowtail flounder, *Limanda ferruginea*, off the New England coast. Change in length was carefully examined in a recent marking experiment conducted in March 1959. At that time 2,100 yellowtail were tagged on fishing grounds off southern New England. In the 2 weeks following tagging, 99 of the fish were recaptured by commercial otter trawlers and given to Bureau of Commercial Fisheries personnel stationed at ports of landing. Total length in millimeters was recorded at the time of tagging and at recovery. Because growth of marked yellowtail between tagging and recovery was to be used to supplement yellowtail growth information determined by other means, it was desirable to obtain accurate information on the amount of shrinkage so that adjustment of lengths of recovered, marked fish could be made.

Obvious mistakes were made in measurements of three fish and these measurements were omitted. Total lengths at time of tagging and changes in length between tagging and recovery of the remaining 96 fish are given in Table 1. Of these, 81 were shorter at recapture than at tagging, 9 were longer, and 6 were unchanged in length. Mean change in length was about —1.2 percent. It is known that fish, when stowed in ice in holds of fishing vessels, shrink as much as 12 percent in weight after death (Cutting, 1951; Harvey, 1953). Cutting (1951) has also shown that a small amount of shrinkage in length also occurs. In his tests this amounted to 0.68 percent for cod, haddock, and plaice, combined. Assuming no growth was added between tagging and recovery in the sample of tagged yellowtail, the shrinkage, aside from measurement errors, can probably be attributed to changes between live and landed lengths.

Table 1.—*Lengths of 96 yellowtail flounder at time of tagging and changes in length[1] between tagging and recapture[2] — expressed in millimeters*

[Negative values indicate a decrease in length]

Total length	Length change	Total length	Length change	Total length	Length change
258	−5	341	−11	360	−2
260	−7	341	−3	361	−2
262	−9	342	0	361	−7
264	−7	342	−7	364	−4
280	−14	344	−4	364	0
281	9	345	−2	364	−6
282	−2	347	8	365	−4
288	9	347	5	365	0
288	−3	347	−4	366	2
293	−6	347	3	366	6
296	9	347	−3	368	−2
307	7	348	−2	369	−5
310	−2	348	−5	373	−3
314	−4	349	1	375	−2
314	−4	350	−7	375	−3
316	−3	350	−8	376	−2
316	−12	351	−6	377	−8
319	5	352	−4	378	−5
321	−1	352	−7	379	−7
322	−7	353	−3	380	−7
323	7	353	−8	382	−10
327	−4	353	−5	384	−18
330	0	353	−5	386	−3
331	−1	353	3	393	0
332	−4	354	−1	393	−5
334	1	354	−4	397	−3
336	−2	356	−6	397	−9
337	−7	357	−5	413	−4
338	2	358	−3	414	−3
340	0	359	−3	419	−6
341	−8	359	−7	442	−5
341	−9	360	−3	461	−6

[1]Mean change in length = −4.03 millimeters (−1.16 percent). Standard deviation = 4.18 millimeters.
[2]All fish were at liberty 2 weeks or less.

The 1.2 percent shrinkage computed for the 96 tagged yellowtail probably does not represent the actual shrinkage for a number of reasons. Some error probably arose from measuring operations since measurements were made by a number of people. In addition, the wide range of length changes between tagging and recovery suggests that mistakes, besides the three noted, were made in measuring. Also, it is possible that a small amount of growth in length was added by some of the fish in the 2 weeks or less they were at liberty following tagging.

It was assumed that the shrinkage occurred between time of capture and time of landing. In normal commercial fishing operations the fish are stored in crushed ice in the vessel's

[1]The author wishes to acknowledge the help of Mr. Raymond L. Fritz, Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts, who assisted in measuring and tagging the fish considered herein.

fish hold during this period. To determine the amount of shrinkage the lengths of 72 live yellowtail from a catch of the Bureau of Commercial Fisheries research vessel *Delaware* were recorded and each fish was identified with a numbered tag. The fish were then placed in ice in the fish hold of the vessel to simulate holding conditions aboard a commercial fishing vessel. After 54 hours the fish were removed from the ice and remeasured. All measurements were made by the same person. Lengths at the first measurement and changes in length between the two measurements are given in Table 2. All fish were shorter at the second measurement. Mean change in length was about −1.5 percent. The length change appeared constant for the entire range of fish sizes.

Variation in the length change in this experiment (standard deviation = 1.48 millimeters) was much less than in the tagged and recaught fish (standard deviation = 4.18 millimeters). Because the measuring and icing experiment was done under conditions where error was probably kept at a minimum, it was believed that the 1.5 percent figure accurately estimated actual shrinkage between live and landed lengths and is of use for adjusting growth data from tagged yellowtail.

It seems likely that similar shrinkage occurs in other fish species. Knowledge of the amount of such shrinkage would be of value in determining growth from tagged fish. In addition, it would be useful in studies where length frequencies of live fish are obtained at sea and are combined with length frequencies of fish that have been stowed in ice in vessel holds for several days.

TABLE 2.—*Live lengths of 72 yellowtail flounder and reductions in length*[1] *after stowage in ice for 54 hours — expressed in millimeters*

Total length	Length reduction	Total length	Length reduction	Total length	Length reduction
269	5	345	5	367	6
275	7	345	7	367	4
280	4	347	4	370	4
297	5	347	4	371	5
320	6	348	4	372	6
325	3	350	3	373	3
328	6	352	3	374	5
328	5	354	4	375	4
329	5	355	9	378	5
330	5	355	4	378	4
330	5	355	5	379	4
335	5	356	6	381	6
335	5	356	4	382	7
337	4	357	9	400	5
337	5	357	4	403	6
338	8	357	7	404	4
340	4	358	6	405	5
340	6	359	5	413	6
342	5	359	6	415	6
342	7	360	7	418	4
342	3	360	6	418	3
342	4	360	9	428	9
344	7	360	7	429	6
344	5	365	5	455	5

[1]Mean change in length = −5.12 millimeters (−1.47 percent). Standard deviation = 1.48 millimeters.

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FRED E. LUX

U. S. Fish and Wildlife Service
Bureau of Commercial Fisheries
Woods Hole, Massachusetts

Food Habits of Burbot

The burbot, *Lota lota* (Linnaeus), is held in high regard in some parts of the country but is seldom used for food in Minnesota. Large numbers are discarded by fishermen who consider them a rough fish and seem surprised when told they are edible. Contrary to Forbes and Richardson (1920), who maintained that the flesh of the burbot was coarse and tasteless, it is excellent as food and was correctly labeled by Adams and Hankinson (1928) as a fish of the future, awaiting only recognition as a desirable food fish.

The food habits of the burbot have been studied extensively by many authors, with most of the work being done on the Great Lakes (Pearse, 1921; Van Oosten and Deason, 1938; Clemens, 1951). Clemens *et al.* (1923, 1924) examined specimens from Lake Nipigon, and Bjorn (1940), who was successful in artificially propagating this species, checked its diet in three Wyoming lakes. The present report concerns burbot collected from Mille Lacs Lake, a large shallow lake in central Minnesota, in December 1949 and during the winter of 1958-59.[1]

The 1949 sample contained 29 females, 20 males, and 1 immature fish, collected on the west shore on December 20. All of the stomachs containing food had fish present. Four of the 56 stomachs were empty. Twenty-three of the 48 stomachs with food (47.9 percent)

[1]Mille Lacs Lake has been described by Malone and Johnson (1957).

contained fish positively identified as perch. Eighty fish were taken from three areas located in the northwest, northeast, and southeast portions of the lake between December 15, 1958, and February 8, 1959, in conjunction with a creel census conducted under Minnesota Dingell-Johnson project F-4-R-6. These fish, which had been caught by ice fishermen and discarded, were picked up and stored frozen until they could be dissected. The diet of the burbot was much the same for both years, with the exception of the burrowing mayfly *(Hexagenia* sp.*)* which was found only in the 1958-59 sample. One-hundred percent of the stomachs which held food contained fish in 1949 and 89.1 percent contained fish in 1958-59 (Table 1).

When both samples were combined it was found that 82.4 percent of the stomachs contained food, not including bait fish. Perch were identified in 53.6 percent of the stomachs with food, while 77.7 percent contained remains of fish too digested for positive identification. Only in one instance was a walleye identified in a stomach and this was from a 16.8-inch burbot collected in 1949. Although positive identification could not be made on stomach contents listed as unidentified fish, in no instance did it appear that the remains were of protected game fish. Johnny darters, sculpins, common shiners, sunfish, golden shiners, common suckers, ciscoes, and creek chubs were found in the stomachs in smaller amounts.

The amount of fish eaten by burbot is prodigious in some cases. One stomach taken in 1958-59 revealed a 4.5-inch burbot, 30 perch, and 1 common shiner (bait). Another contained 40 perch, an unidentified fish, and 1 common shiner. Although these stomachs were exceptional and only a few contained such volumes, the largest volume recorded was 80 milliliters, made up of 12 *Cottus* sp., 10 crayfish, 3 unidentified fish, and 1 common shiner (bait). Most of the young-of-the-year perch in the stomachs were between 2.5 and 3.5 inches long.

The primary food of the burbot in Lake Mille Lacs during the winter months is perch, with darters, cyprinids, and sculpins among the vertebrates and crayfish and mayfly larvae, among the invertebrates, as a secondary food. Since competition between the burbot and walleye undoubtedly exists and the burbot's role in the dynamics of certain lakes must be considered, its value both as a predator and a food source should be given further consideration.

TABLE 1.—*Number and percentage of fish containing various food items in a sample of 136 burbot from Mille Lacs Lake—1949 and 1958-59*

[Percentage shown in parentheses]

Item	1949	1958-59	Combined
Total number of stomachs	56	80	136
Empty stomachs	4 (7.1)	12 (15.0)	16 (11.8)
Stomachs with food, including bait	52 (92.9)	68 (85.0)	120 (88.2)
Stomachs with food other than bait	48 (85.7)	64 (80.0)	112 (82.4)
Fish	48 (100.0)	57 (89.1)	105 (93.8)
Unidentified fish[1]	39 (81.2)	48 (75.0)	87 (77.7)
Perca flavescens	23 (47.9)	37 (57.8)	60 (53.6)
Notropis cornutus	5 (10.4)	2 (3.1)	7 (6.2)
Etheostoma nigrum	2 (4.2)	5 (7.8)	7 (6.2)
Cottus sp.	3 (6.2)	4 (6.2)	7 (6.2)
Lepomis sp.	—	2 (3.1)	2 (1.8)
Catostomus commersoni	2 (4.2)	—	2 (1.8)
Lota lota	—	1 (1.6)	1 (0.9)
Notemigonus chrysoleucas	1 (2.1)	—	1 (0.9)
Semotilus sp.	—	1 (1.6)	1 (0.9)
Coregonus artedi	1 (2.1)	—	1 (0.9)
Stizostedion vitreum	1 (2.1)	—	1 (0.9)
Invertebrates	2 (4.2)	19 (29.7)	21 (18.8)
Hexagenia sp.	—	14 (21.9)	14 (12.5)
Crayfish	2 (4.2)	6 (9.4)	8 (7.1)
Unidentified insects	—	1 (1.6)	1 (0.9)
Vegetable matter	1 (2.1)	4 (6.2)	5 (4.5)
Debris	1 (2.1)	3 (4.7)	4 (3.6)

[1]In all cases these appeared to be perch or minnows.

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Thomas Bonde
J. E. Maloney

Minnesota Department of Conservation
St. Paul, Minnesota

Establishment and Early Dispersal of a Loach, *Misgurnus anguillicaudatus* (Cantor), in Michigan

Treatment with rotenone and toxaphene of a private pond on Hy Meadow farm near Holly, Oakland County, Michigan, in July 1958, by Wayne Tody and Bruce Vollmar of the Michigan Department of Conservation, revealed a large population of a small, unfamiliar, eel-like fish. Specimens were submitted to the Museum of Zoology of the University of Michigan where their identity as Oriental weatherfish (or the dojo), *Misgurnus anguillicaudatus* (Cantor), was confirmed by Dr. Reeve M. Bailey. A check of records indicated that six specimens of the same species were sent to the Museum of Zoology for identification from the Sunset Water Gardens, an aquarium supply concern of Holly, Michigan, on July 4, 1939. They were part of a shipment received from Kobe, Japan. The Sunset Water Gardens utilizes Sunset Pond as a rearing and retaining area. Since Sunset Pond is less than a mile from Hy Meadow Pond (Figure 1), and since both drain into the same intermittent stream, it seems obvious that escaped fish are responsible for this successful establishment, presumably about 19 years prior to the present capture. In 1951, Hy Meadow Pond was deepened by dredging and an earthen dyke was constructed across the outlet channel to prevent overflow, so entrance of the dojo into the pond was almost certainly before that time. The owner of the pond was unaware of the occurrence of the fish. This record represents the first successful introduction of any species of the family Cobitidae (loaches) in the New World.

In order to determine the extent of dispersal, 16 fish collections were taken in the Shiawassee River system (Figure 1). A three-man stream-survey crew made collections with a 2,500-watt direct-current shocker on September 15, 18, and 23, 1958, and August 18-20, 1959. Six collecting stations were upstream and 10 downstream from Hy Meadow Pond. The shocker was used in all parts of the river at each station, but particular emphasis was directed to the habitat in which most dojos were found, that is, standing or sluggish water in marsh areas adjacent to flowing water.

Dojos were collected at 5 of the 16 stations (Figure 1 and Table 1), indicating a continuous distribution throughout at least 10 miles of a section of the stream that passes through six lakes. The lakes in Holly and Fenton are impoundments, but the dams did not prevent downstream movement of the fish. Since dojos were not found at four localities above station 5 or at five stations below station 11, it is believed that the collections delimit the present range of the species in the watershed.

The size range of the fish (1.2 to 7.1 inches, total length) proves that dojos reproduce successfully in the watershed. The fact that

TABLE 1.—*Number of dojos and other fish collected with a direct-current shocker in the Shiawassee River at the stations shown in Figure 1*

Station number	Date of collection	Minutes of shocking	Number of dojos	Number of other fish
1	8/18/59	25	0	53
2	8/18/59	15	0	4
3	8/18/59	15	0	80
4	9/18/58	15	0	65
5	8/18/59	20	10	43
6	9/15/58	20	43	43
7	8/19/59	10	0	32
8	9/18/58	15	8	36
9	9/18/58	20	8	35
10	8/19/59	10	0	13
11	8/19/59	30	1	57
12	8/20/59	20	0	34
13	8/20/59	35	0	63
14	9/23/58	20	0	18
15	9/23/58	15	0	20
16	9/23/58	25	0	47

dojos were collected in both September 1958 and August 1959 verified their survival of the weather extremes in southern Michigan during this period.

EDWARD E. SCHULTZ

Institute for Fisheries Research
Michigan Department of Conservation
Ann Arbor, Michigan

Predation of Young Coho Salmon on Sockeye Salmon Fry at Chignik, Alaska[1]

Two species of Pacific salmon are found in abundance in the Chignik lakes. Sockeye salmon *(Oncorhynchus nerka)* is the commercially desired species, and in the 1920's this run averaged around 2 million fish annually. Recently runs have averaged only 800,000 fish. The other species, coho salmon *(Oncorhynchus kisutch)*, was also harvested in former years with runs of around 100,000 fish. In recent years (1949-1953) the coho returning to the system averaged 40,000 fish with the commercial catch forming only a small portion of the run.

The decline in sockeye runs has prompted investigation of factors causing mortality to young sockeye salmon during fresh-water residence. In the course of this study it was necessary to consider all other species of fish

[1]Contribution No. 42, College of Fisheries, University of Washington, Seattle, Washington.

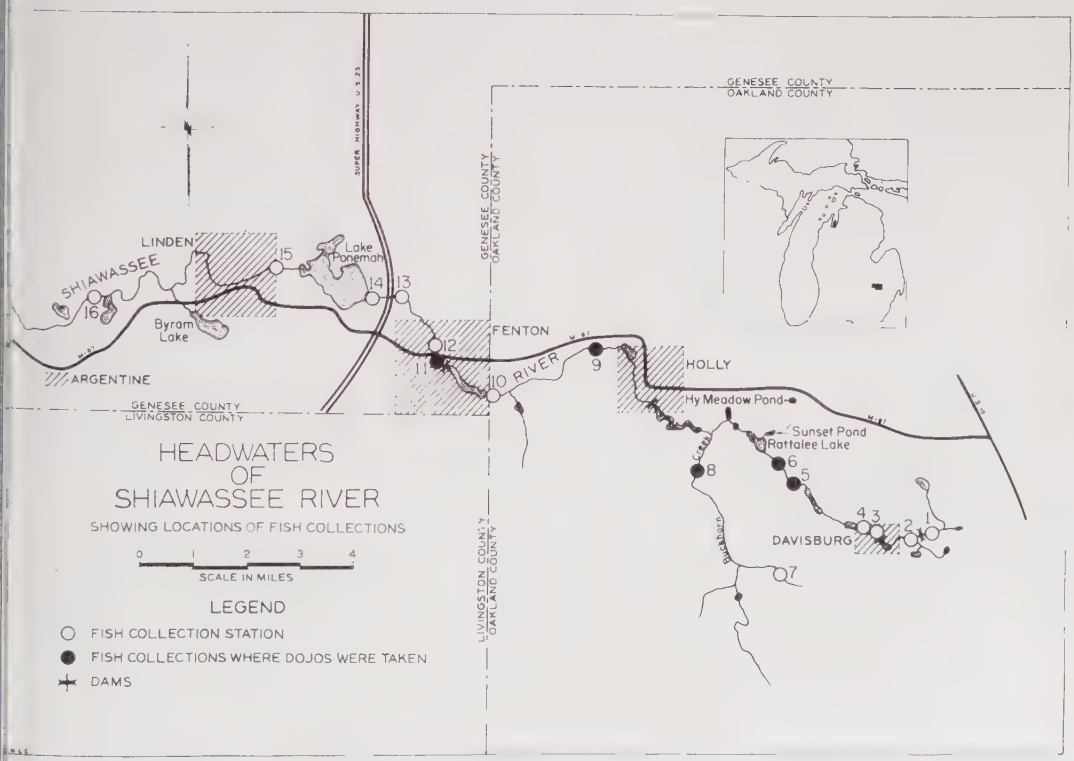

FIGURE 1.—Map of the headwaters of the Shiawassee River, Oakland and Genesee counties, Michigan, showing stations where dojos were collected (solid circles) or were not taken (open circles).

in the lakes as possible predators and food competitors. Investigations of Dolly Varden *(Salvelinus malma)* at Chignik (Roos, 1959) have shown that they are predators of juvenile sockeye salmon. Stomach analysis of coho fingerlings, collected during the summers of 1956, 1957, and 1959, has revealed that coho salmon also prey upon sockeye salmon fry. Such predation has previously been reported from Cultus Lake, British Columbia, by Ricker (1941) for residual (200-400 millimeters long) coho salmon.

The two lakes of the Chignik system lie on the Alaska Peninsula, some 200 miles west of Kodiak Island. Both lakes are small with surface areas of 9 and 15 square miles and less than 100 feet above sea level. Black Lake (upper lake) is shallow (less than 25 feet), whereas Chignik Lake (lower lake) is deep (maximum depth, 190 feet). Fourteen species of fish have been found in the lakes. Sockeye salmon is the most abundant species of salmon. The coast-range sculpin *(Cottus aleuticus)*, threespine stickleback *(Gasterosteus aculeatus)*, Dolly Varden, and coho salmon are other abundant species.

Coho salmon were collected with a beach seine from the two lakes during May, June, and July. One hundred and eighty-two preserved specimens (10 percent formalin) were measured for standard length and the stomach contents from esophagus to pylorus identified. Numbers of sockeye salmon fry were recorded, and individual food items other than fish were not counted nor were measurements of volume or weight of food obtained. Results are expressed as frequency of occurrence, obtained by dividing the number of fish containing a specific food by the total number of fish inspected.

Of all fish examined, 97 percent had food in their stomachs at time of capture (Table 1). In most instances stomachs were distended. Eighty-seven percent of the stomachs examined contained insects, of which Diptera larvae were the most prevalent. Thirty percent of the cohos fed on sockeye salmon fry, with an average of 2.3 fry per stomach or an average of 0.7 sockeye salmon per stomach for all fish examined. This incidence is seven times the number of juvenile sockeye salmon found in Dolly Varden stomachs (Roos, 1959). The maximum number of sockeye fry in any one coho salmon stomach was seven. Fry were found in various stages of digestion indicating that predation had taken place prior to the time of the seine haul.

TABLE 1.—*Stomach content of coho salmon taken at Chignik, Alaska, in 1956, 1957, and 1959*

Item	Number of fish with food item				Percentage occurrence (all fish)
	1956	1957	1959	Total	
Sockeye salmon fry	2	4	48	54	29.7
Diptera larvae	22	19	100	141	77.5
Trichoptera	3	—	9	12	6.6
Plecoptera	—	—	1	1	0.5
Coleoptera	—	1	1	2	1.1
Unidentified insects	—	1	2	3	1.6
Amphipods	3	—	14	17	9.3
Oligochaeta	1	—	1	2	1.1
Araneae	—	—	1	1	0.5
Miscellaneous items	2	3	6	11	5.9
Number of empty stomachs	0	4	1	5	2.7
Number of fish feeding	25	22	130	177	97.3
Total examined	25	26	131	182	—

The young coho salmon included two age groups, both of which fed on young sockeye salmon (Figure 1). It would therefore appear that each year class preys upon sockeye salmon for two seasons.

Inspection of stomachs of sockeye fingerlings (age-groups I and II) captured with the young coho revealed that they were feeding upon insects. It appears that young coho are also food competitors with sockeye salmon.

Sticklebacks were not found in the coho salmon collected at Chignik even though they composed 54 percent of fish in the seine hauls of which young sockeye made up 35

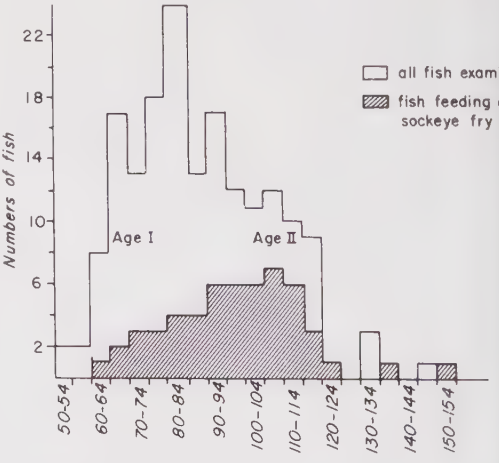

FIGURE 1.—Size-frequency distribution of young Chignik coho salmon examined for stomach contents and those which ate sockeye fry.

ercent and young coho 11 percent. These data indicate that young coho in the Chignik system prefer young sockeye salmon over sticklebacks as a source of food. All evidence gathered to date at Chignik suggests that coho salmon are more detrimental than beneficial to sockeye salmon.

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JOHN F. ROOS[2]

isheries Research Institute
niversity of Washington
eattle, Washington

[2]Presently with International Pacific Salmon Fisheries Commission, New Westminster, British Columbia, Canada.

Age and Growth of Four Species of Warm-Water Game Fish from Three Montana Ponds[1]

A considerable number of ponds, lakes, and streams in Montana have been stocked with various species of warm-water game fish. In most instances low water temperatures and short growing seasons have precluded satisfactory growth of these fishes but not their ability to reproduce and compete with cold-water species. Many largemouth bass *(Micropterus salmoides)*, bluegills *(Lepomis macrochirus)*, black crappie *(Pomoxis nigromaculatus)*, and yellow perch *(Perca flavescens)* became available for an age-and-growth study when three gravel-pit ponds near Three Forks, Montana, were poisoned for the removal of these species (July 17-18, 1957).

Wollitz[2] has given a complete description of these ponds and the effects of toxicants on their fish and fish-food organisms. These ponds lie adjacent to one another, are without inlets or outlets, and depend upon seepage for their water supply. Daytime maximum summer (mid-July to mid-August) water temperatures at the surface varied between 65° and 75° F. Surface water usually cools considerably at night and sub-surface temperatures were usually 2°—6° F. cooler than those at the surface during the day. There was no marked thermal stratification and frequent wind-induced circulation of water occurred throughout the ice-free period. The period of ice-cover is ordinarily from early November to the early part of April.

The East Pond is over 30 years old, the Middle Pond over 25 years, and the West Pond, while dredging began about 20 years ago, is still in use for gravel dredging at the present time. The areas, maximum depths, and fish present at the time of poisoning are shown in Table 1.

TABLE 1.—*Size, depth, and fish species for the Three Forks Ponds*

Item	East Pond	Middle Pond	West Pond
Area (acres)	12.9	23.3	12.8
Maximum depth (feet)	12	18	19
Fishes[1]	Yellow perch Bluegill Largemouth bass Black crappie Carp Longnose sucker Common sucker Golden shiner	Bluegill Yellow perch Black bullhead Black crappie Largemouth bass Carp White sucker	Yellow perch Bluegill Largemouth bass

[1]Fishes listed in decreasing order of abundance.

The fish used in the age-and-growth study were randomly selected for size from several thousand specimens picked up after the ponds were treated with toxicants. Total length measurements were made to the nearest 0.1 inch and weights to the nearest 0.01 pound. Sex was determined on mature fish but age-and-growth data are not separated by sex since they showed no important differences. Scales were taken from the area between the dorsal fin and lateral line. Scale impressions were made on plastic, and annuli were determined and increments measured along the anterior radius after the scales were projected. A constant ratio of scale radius to body length was assumed in the calculations.

[1]Contribution from Montana State College Agricultural Experiment Station, Project No. MS844, Paper No. 490 Journal Series.

[2]Wollitz, Robert E. (1958) The effects of certain commercial toxicants on the limnology of three cold water ponds near Three Forks, Montana. Thesis. Montana St. Coll., 63 pp.

LARGEMOUTH BASS

The average calculated length at each annulus shows very slow growth in all three ponds (Figure 1, Table 2). This species grew slightly faster in the West Pond. A useful size (10 inches) was not reached until the fifth year, and a weight of 1 pound was not achieved until the sixth or seventh year. The total number of largemouth bass recovered, 12 inches or over in total length, was as follows: East Pond, 15; Middle Pond, 15; West Pond, 12. The longest fish was 16.2 inches in total length and weighed 2.6 pounds. The heaviest fish was a female, 16.1 inches long and weighing 3.3 pounds.

Previous work on the age and growth of Centrarchidae in Montana is limited to the study of a few specimens from three ponds in eastern Montana (Brown and Thoreson, 1951). Twenty-two largemouth bass from these ponds showed an average calculated total length of 2.1 inches at the first annulus. This is slightly better than the Three Forks ponds which had an average of 1.9 inches. Growth was much faster in Baugh Pond (Brown and Thoreson, 1951) where largemouth attained a length of 7.4 inches at the time of second annulus and 10.3 inches a[t] the third.

We found no record where largemouth bass[e] grew as slowly as determined for Three Fork[s] ponds. Weyer (1940) reported this species t[o] reach 10.5 inches at the third annulus. Thi[s] same length was reached at the third annulu[s] in Wisconsin (Bennett, 1937). In Minnesota [it] it attained 9.3 inches at the third annulus an[d] in Oklahoma (Jenkins and Hall, 1953) a[n] average length of 9.7 inches was achieved a[t] the second annulus. Stroud (1948) reporte[d] 12.2 inches at the second annulus for Tennes[see].

BLUEGILL

Bluegills, like largemouth bass, showe[d] slow growth. They did not reach a total length of 5 inches until their fifth year (Figure 1, Table 2). Bluegills from the Middle Pond were larger than the others at annuli I and II but those from the West Pond were larger at annuli III and IV. The largest bluegill re-

[3]Moyle, John B., and Charles R. Burrows. (1954) Manual of instructions for lake survey. Minn. Dept. Cons., Fish. Res. Unit, Spec. Publ. No. 1, 70 pp.

TABLE 2.—*Calculated total lengths in inches at the end of each year of life of largemouth bass, bluegill, black crappie, and yellow perch from three ponds in southwestern Montana*

[Number of specimens in parentheses]

Species	Ponds	Year of life									
		I	II	III	IV	V	VI	VII	VIII	IX	X
Largemouth bass	East	2.0 (52)	3.7 (40)	5.6 (34)	7.7 (28)	9.3 (20)	10.9 (17)	12.3 (15)	13.2 (12)	14.0 (6)	13.8 (3)
	Middle	1.8 (61)	3.7 (54)	5.5 (51)	7.4 (47)	10.0 (28)	11.7 (23)	13.4 (15)	14.3 (10)	15.2 (5)	—
	West	2.0 (45)	4.2 (31)	6.2 (27)	8.5 (20)	10.4 (17)	12.0 (12)	13.3 (8)	14.3 (6)	15.8 (1)	—
	Average	1.9 (158)	3.8 (125)	5.7 (112)	7.7 (95)	9.9 (65)	11.5 (52)	12.9 (38)	13.8 (28)	14.7 (12)	13.8 (3)
Bluegill	East	1.7 (67)	2.9 (39)	4.0 (35)	4.7 (29)	5.2 (14)	5.6 (2)	6.6 (1)	—	—	—
	Middle	0.8 (25)	1.8 (25)	2.8 (22)	3.8 (21)	4.7 (14)	5.3 (10)	6.0 (4)	6.9 (1)	—	—
	West	0.8 (27)	2.2 (20)	4.8 (5)	5.7 (2)	—	—	—	—	—	—
	Average	1.3 (119)	2.4 (84)	3.6 (62)	4.4 (52)	5.0 (28)	5.4 (12)	6.1 (5)	6.9 (1)	—	—
Black crappie	East	1.0 (29)	2.2 (29)	3.3 (28)	4.3 (25)	5.4 (13)	6.8 (6)	6.9 (1)	—	—	—
	Middle	1.3 (26)	2.6 (22)	4.3 (21)	5.5 (19)	6.1 (12)	6.5 (7)	7.1 (2)	—	—	—
	Average	1.1 (55)	2.4 (51)	3.7 (49)	4.8 (44)	5.7 (25)	6.6 (13)	7.0 (3)	—	—	—
Yellow perch	East	1.9 (18)	3.5 (14)	4.6 (13)	4.9 (8)	5.5 (1)	—	—	—	—	—
	Middle	2.0 (22)	3.3 (15)	4.1 (14)	4.8 (7)	5.7 (4)	—	—	—	—	—
	West	2.4 (43)	4.8 (31)	7.0 (27)	8.5 (23)	9.7 (17)	10.7 (3)	—	—	—	—
	Average	2.2 (83)	4.1 (60)	5.7 (54)	7.1 (38)	8.8 (22)	10.7 (3)	—	—	—	—

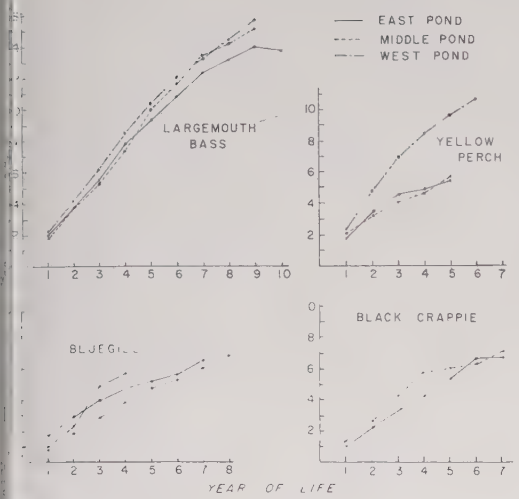

FIGURE 1. — Average calculated total length in ches at each annulus for largemouth bass, bluegills, ack crappie, and yellow perch for each of the Three rks Ponds.

vered was a male 7.3 inches long from the iddle Pond which weighed 0.3 pound. own and Thoreson (1951) reported on 43 uegills taken from six eastern Montana rm ponds. Their average growth was some- at higher than that of fish from the Three orks Ponds with an average total length of 3 inches at the third annulus.

Bluegills from Ohio showed even poorer owth than those from the Three Forks ponds Evans, I. M., cited by Carlander, 1953). ey did not reach 5 inches in total length til the fifth annulus. Some fish from Mis- uri averaged 2.6 inches at their third an- lus, but no older specimens were reported Veyer, 1940). In contrast, a size of more an 5 inches in total length at the second nulus has been reported (I. M. Evans, cited Carlander, 1953; Upper Mississippi River nservation Committee[4]; Roach[5]).

BLACK CRAPPIE

Calculated total lengths of crappie (Figure Table 2) show that it reached a useful size 6 inches during the fifth summer. There s little difference between the growth rate the East and Middle ponds, and the species was absent from the West Pond. The largest specimen taken was 8.2 inches and weighed 0.27 pound and the oldest specimens (three) had seven annuli and averaged 7.0 inches in total length.

Black crappies from Raymond Reservoir in eastern Montana (Brown and Thoreson, 1951) grew much faster and reached 6 inches in total length late in their third year. In certain other states the average calculated total length at the third annulus is as follows: Minnesota[6], 6.8 inches; Ohio (Roach, 1948a), 9.2 inches; and Tennessee (Stroud, 1948), 11.8 inches.

YELLOW PERCH

The average calculated total length of perch at the third annulus was 5.7 inches (Figure 1, Table 2). Growth was much more rapid in the West Pond where 7.0 inches was attained at this annulus. The largest specimen taken was a female 11.2 inches long and weighing 0.75 pound, and the oldest specimens had six annuli and averaged 10.7 inches in total length. All of the larger fish came from the West Pond. In several thousand perch recovered from the East and Middle ponds, all were less than 6 inches long.

Yellow perch from Raymond Reservoir (Brown and Thoreson, 1951) in eastern Montana reached 6.6 inches at their third annulus. Those from Lower Thompson Lake (Echo, 1955) in western Montana averaged only 4.4 inches at the third annulus.

In other states the calculated total lengths at the third annulus were: Ohio (Roach, 1948b), 5.5 inches; Minnesota[7], 6.0 inches; Connecticut (Webster, 1942), 7.7 inches; Lake Erie, Ohio (Jobes, 1952), 8.5 inches; Iowa (Lewis, 1950), 10.3 inches.

The relatively better growth of yellow perch, bluegills, and largemouth bass in the West Pond is attributed to the smaller population there. It is surmised that dredging operations have interfered with reproduction and that this pond has not attained its ultimate numerical capacity.

[4]Upper Mississippi River Conservation Committee. (946) Second progress report of the Technical nmittee for Fisheries. 27 pp. Mimeo.

[5]Roach, Lee S. (1949) Lake management reports Meander Lake. Ohio Div. Conserv., 37 pp. Mimeo.

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[7]See footnote 6.

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C. J. D. Brow[n]
Sidney M. Log[an]

Montana State College
Bozeman, Montana

REVIEWS

SH-WATER BIOLOGY. *By Henry B. Ward and George C. Whipple. Second edition edited by W. T. Edmondson. John Wiley & Sons., Inc., New York. 1959. 1248 pp. $34.50.*

his fine book, dedicated to Dr. G. Evelyn Hutchinson, brings this fresh-water "bible" up to date for se concerned with aquatic organisms. First published in 1918 by John Wiley and Sons, the 27 collaborors to the old volume are replaced by 51 contribrs to this new and greatly expanded edition. Two he original contributors to the 1918 edition, Dr. R. Coe (nemerteans) and Dr. J. Percy Moore rudineans) revised their sections for the new edi-

As stated on page 1 of the Introduction, the book nsists of a series of illustrated keys to the fresher flora and fauna of North America north of the Grande, each preceded by a statement of informa- necessary to its correct use."

he old edition contained 1111 pages while the v totals 1248 pages with materials expanded to inle much new knowledge of aquatic plants and mals accumulated since the original publication. instance, present sections on fungi, bryophytes, ligrades, and polychaetes were omitted in the first tion. Aquatic vertebrates and internal parasites are ntly omitted because of space limitations and the t that the last named are not truly aquatic. Freeming cercaria larvae (trematoda) and spiders asiated with water are also omitted. The sections on teria, algae, protozoa, gastrotrics, branchiopods, ostods, copepods, malacostracans, mites, aquatic ints, and vascular plants have been greatly expanded. ult terrestrial forms with immature under-water ges have been omitted, probably because of space itations and the fact that excellent monographs are ilable with which to identify them.

he section on water mites is based on a careful vey of the literature and contains an exceptional nber of unsupported opinions that show considere insight and may well prove to be true. As an rnative to his laborious enzymatic method of preing specimens, Newell recommends a poor proce- re and neglects a much superior method that has n used by every mite specialist since Köenike. The t that the number of genera increased by some 25 rcent (none of it due to splitting) while the key s in manuscript form, is a measure of its obsoscence. Unfortunately, many extensive additions to known fauna came in the period between prepaion and publication of the manuscript, making issions unavoidable.

eeing again many of the figures that appeared in first edition was like meeting old friends which the latter, showed some signs of wear. Even so, st of the chapters contain many new and generally ellent illustrations. In an apparent effort to keep index small, numerous terms used in the text are itted—such items as whirligig beetle, ligula, compnd eye, birotulate, and trichocyst.

I have the feeling that this book may be the last of its kind. There is now too much available knowledge on fresh-water organisms to get it into the confines of a single book. The decision to omit the vertebrates was probably for this reason. Another feature reduced in scope from the first edition was the discussion of the ecology and habits of each group. As Dr. Edmondson says in the preface, "It was obvious that to maintain as convenient a size as possible, a change in the approach would have to be made. . . . It can no longer serve as a textbook of general biology, or of the principles of limnology."

Space might have been saved if less exhaustive bibliographies had been given. For instance, the bibliography for the Rotifera occupies 4½ pages of fine print while that for all aquatic diptera fills slightly over half a page. This points up the obvious fact that treatment of the various groups is not consistent, nor could this be expected where 46 separate sections were written by different authors. However variable the treatment, one cannot but be impressed with the vast amount of effort that went into the preparation of this book. Dr. Edmondson is to be congratulated for serving as the organizer of the specialists concerned and for the guidance and inspiration provided. Its price is its worst feature. Even so, this book will be of tremendous service over the years to those interested in fresh-water biology.

PAUL R. NEEDHAM

Department of Zoology
University of California
Berkeley, California

THE BIOLOGY OF POLLUTED WATERS. *By Hugh B. N. Hynes. University Press of Liverpool, Liverpool, England. 1960. 202 pp. 25s.*

Like the roots and branches of Ygdrasil, the mighty ash-tree of Norse mythology, the ramifications of pollution biology extend far and encompass much. Although fisheries biologists are often concerned with pollution and its abatement, few are thoroughly at home in all the many disciplines of this field and the interrelationships between them. In such a complex field this readable summary of the present state of our knowledge is especially welcome.

As Senior Lecturer in Freshwater Zoology in the University of Liverpool, the author has had much experience investigating pollution and its effects in Britain. This is not a textbook; unlike many other books and publications in the field, it touches lightly on techniques, methods, and systematics, rather its approach is that of aquatic ecology. Students of aquatic biology will find this ecological approach interesting and profitable reading.

Special emphasis is placed on the biological assessment of pollution for, as the author points out, pollution is essentially a biological problem even

though in the past the pollution biologist has often had to play second fiddle to the chemist. Systems for classifying waters and assessing pollution are discussed, and the "Saprobiensystem" used in continental Europe is considered in some detail. The author stresses the necessity for study and evaluation of each problem and situation on its own merits, his philosophy being that, "In nature little is simple and straightforward, and a rigid system can lead only to rigidity of thought and approach."

The 14 chapters begin with a *History of Water Pollution* (it started early in Britain) and end with *The Prospects for the Future* (the author is fairly optimistic). The sections on sewage fungus, aquatic botany, pollutional effects of detergents and heavy metals, and the discussion of biological oxygen demand are especially interesting. Aquatic entomologists will also find much of special interest to them. Literature coverage is broad; the 15 pages of references include the more important European and North American papers on pollution biology. There are both author and subject indexes. The illustrations include photographs of the several kinds of organisms generally called "sewage fungus," and drawings of some of the common invertebrates and algae of English streams. This attractive, well-printed book, free from typographical errors, should prove a useful and readable addition to the library of the aquatic biologist.

JOHN B. MOYLE

Department of Conservation
State of Minnesota
St. Paul, Minnesota

SEALS, SEA LIONS, AND WALRUSES; A REVIEW OF THE PINNIPEDIA. *By Victor B. Scheffer. Stanford University Press, Stanford, Calif. 1958. 179 pp., 15 figs., 32 plates, 3 tables. $5.00.*

This very concise review admirably summarizes current knowledge on the biology of the Pinnipedia throughout the world. Emphasis is upon taxonomy, systematic relationships, and geographical distribution, but a fine opening chapter summarizes the biology of the group as a whole. The greater part of the book is taken up with the systematic account and a synoptic key to the genera, but there are chapters on characteristics of pinnipedes, their evolution, and the taxonomic procedure. The brief introduction includes a table with the author's estimated world populations of the 31 species and 16 subspecies which he recognizes. The estimates, based upon the literature review plus the findings presented at North Atlantic Seal Conferences in 1955 and 1957 which were attended by scientists from Canada, Japan, USSR, and the United States, suggest a world population of between 15 and 25 million individuals.

Dr. Scheffer's very important contribution is to indicate the status of knowledge on the entire group and to present a modern "conservative" classification. He makes a special point of the need for the latter "for the reason that the seals, sea lions, and walruses are of growing interest to man, and the sooner the scientific names become accepted in world language the sooner can nations agree upon international measures for conserving their populations." His clear descriptions of his concept of the genus, and [illegible] species and subspecies in the Pinnipedia, in t[illegible] chapter on taxonomic procedure, will be of inter[illegible] and value to students of other groups.

Although the material is condensed to a fault, [illegible] that little space is available for human interest m[illegible] terial, the author does reward the careful reader w[illegible] some items, frequently quotations, which suggest t[illegible] fascinating richness of the literature. A 200-year-[illegible] quotation from Linnaeus states that "they . . . sw[illegible] low stones to prevent hunger, by distending t[illegible] stomach." Naumov, a frequently quoted Russian a[illegible] thority on pinnipedes, is the source in a 1933 p[illegible] lication of the statement, "It is said that sea lio[illegible] sometimes invade fur-seal rookeries in the Co[illegible] mander Islands and violate the females there. The [illegible] sulting progeny yield very poor fur and care[illegible] therefore taken to destroy them on fur-seal farm[illegible] Scheffer goes on to say that he "knows of no c[illegible] of interbreeding between these two genera on t[illegible] Pribilof Islands, . . . where the two animals bre[illegible] side by side and where their behavior has been ca[illegible] fully watched for more than a half century." El[illegible] where, however, successful matings in captivity [illegible] tween *Arctocephalus pusillus* and *Zalophus calif[illegible] nianus*, are mentioned. "These matings represent [illegible] terfertility between members of two closely rela[illegible] subfamilies."

Dr. Scheffer has performed a valuable service [illegible] zoologists in this meticulous review of an excepti[illegible] ally interesting group of mammals. The Natio[illegible] Science Foundation and Colorado State Univers[illegible] should also be congratulated for their support of t[illegible] project. Conservationists would welcome a sister v[illegible] ume which summarized the conservation proble[illegible] but as the author states in his introduction, that v[illegible] not the purpose of the present work.

GUSTAV A. SWANS[illegible]

Department of Conservation
Cornell University
Ithaca, New York

ANIMAL NAVIGATION. *By J. D. Carthy. George Al[illegible] & Unwin Ltd., London. 1957. 151 pp. 18s.*

Rarely, in scientific and social circles, does [illegible] mystery of homing fail to excite interest and indi[illegible] discussion. I know of no easier way to acquire [illegible] speaking knowledge of how animals find their w[illegible] home than to spend a day with Dr. Carthy's book[illegible]

That part of the book on navigation (the ability [illegible] head for home from unknown territory by true na[illegible] gation) is only a small segment, namely, that [illegible] voted to the homing pigeon, the only animal [illegible] which true navigation has been established.

Fascinatingly told, are the examples of how a[illegible] mals find their way about by scent, trial and err[illegible] and the sun and stars. Butterflies, bees, snails, s[illegible] mon, eels, plovers, the shearwater, and others [illegible] molded into his broad array of accounts dra[illegible] widely from the literature and brought up to da[illegible] Unfortunately, it is impossible to verify his interp[illegible] tation of these accounts because no bibliography [illegible] listed. Frequently an author is given whose origi[illegible]

orks most biologists will be able to locate readily any good library.

From original sources he has redrawn pertinent gures or reproduced photographs or drawings help- l to a better understanding of the text.

Particularly thorough are his sections on bees and rds. Knowledge of homing in dogs is to be found rincipally in German and Dr. Carthy's transliterа- n is faithful.

Most fishery scientists will know more about sal- on and eel migration than Dr. Carthy relates in 16 ges.

ARTHUR D. HASLER

iversity of Wisconsin
adison, Wisconsin

NDOCRINE CONTROL IN CRUSTACEANS. *By David B. Carlisle and Sir Francis G. W. Knowles. Cambridge University Press, London. 1959. 120 pp., 18 figs., 5 plates. $3.75.*

In these days of increasing commercial interest in ustacea, it is encouraging to find parallel scientific terest. Indications of increasing scientific concern e found both in this volume and in the more re- ntly published *Crustacea* (T. H. Waterman, ed., ademic Press). Although neither volume is slanted ward the commercial fisheries, the basic physiology esented in both may well yield clues that will entually increase crustacean fisheries.

The neurosecretory system of the head and thorax; lor changes; the pericardial organs and heart beat; owth, molting, development, and metabolism; sex all are presented clearly and succinctly. The his- rical approach is followed, beginning with the work Perkins and of Koller who independently found 1928 that color changes in decapods are regulated substances circulating in the blood. Some confus- g terms of earlier authors have been clarified (the -organ" of Hanstrom and the medulla terminalis -organ" of later workers), and phylogenetic rela- nships of the endocrine systems in crustacea are mmarized. The figures and color plates (of excep- nal quality) do much to aid the reader in under- anding.

To those of us especially interested in shrimp, it ay be noted that *Penaeus* is mentioned only once— studies of *Penaeus braziliensis* for the purpose of rrelating physiological activity with histological ructure of the post-commisure organs. This is not speak slightingly of Knowles and Carlisle, but ther to emphasize how few basic physiological data e available concerning Texas' most important com- ercial species.

Not only is past work well described, but some of e problems yet to be solved are defined. For exam- e, the classic ablation experiments of vertebrate ndocrinology are not useable in many cases because the amount of nervous tissue that must be re- oved,

"We believe that in the study of neurosecre- tory systems new standards may have to be de- vised, and that they will probably rest mainly on the correlation of histologically observable changes to experimentally altered conditions, considered in relation to the identification of active substances in extracts of the suspected secretory tissues and the effects of these substances on target organs." (p. 59)

and the relationships of metabolism and molting.

" . . . it would be well to consider some of the metabolic processes which change throughout the moult cycle and which appear to be under normal control. Since these changes are so closely associated with the moult cycle, it may seem probable that their control is by means of the same hormones which regulate the moult cycle, but there is no guarantee of this and we have not the information available to decide the question." (p. 87)

The authors suggest that much can be done in the fourth decade of crustacean endocrinology with studies of organ structure by the electron microscope and by the biochemical investigation of hormones.

"Finally is it too much to hope that by combining our increasing knowledge of crustacean hormones with the data of insect and vertebrate endocrinology we may perhaps eventually obtain some insight into the basic nature of hormones and their evolution?"

The bibliography of 13 pages includes the pertinent references through 1957, and the volume is concluded with a comprehensive index. Altogether this volume can be heartily recommended to all interested in crustacea and to endocrinologists, both vertebrate and invertebrate.

ZOULA P. ZEIN-ELDIN

Biological Laboratory
U. S. Bureau of Commercial Fisheries
Galveston, Texas

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IN MEMORIAM

Gerard Bourret, Rimouski, Quebec

Col. Carl R. Fellers, Amherst, Massachusetts

Austin A. Roberts, Carlsbad, New Mexico

George K. White, East Orland, Maine

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